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ABSTRACT

The purpose of this study was to document and analyze teachers' and students' activities during physics practicals in order to gain critical insights into why students did not acquire the expected practical skills and how theory and practice interacted in the context of teaching for the practical examination in physics. The study involves three classes (n=116) and three physics teachers at three secondary schools in Freetown, Sierra Leone. Data obtained included observations from four physics lessons, five physics practical classes, and one laboratory demonstration, as well as from nine interviews. Data were analyzed and discussed in light of the teaching methods and barriers that seemed to inhibit students' understanding of scientific concepts. The study suggests several reasons why students failed to acquire basic scientific laboratory skills and knowledge. The teaching of physics is compartmentalized into "theory" and "practical" and these are taught as separate and unrelated entities. The formal examination system, which dominates the thinking of teachers and students alike, promotes this division and strongly influences the teaching methods employed by schools. Included in this study are: (1) an introduction to the study, research setting and participants; (2) literature review and research methods; (3) a description of the laboratory practical work performed in each school, along with the perspectives of teachers and students; (4) the analysis and interpretation of the data; and (5) conclusions and recommendations. Appended are transcriptions of the lessons, demonstrations, and interviews with students and teachers and a copy of the West African Examination Council Physics 1 Practical. (KR)

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THE COMPLEXITIES OF PRACTICAL WORK IN PHYSICS TEACHING:

A CASE STUDY OF THREE SECONDARY SCHOOLS IN SIERRA LEONE

by

Jonathan N. Keister

A thesis submitted to the Faculty of Education

in conformity with the requirements for

the degree of Master of Education

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Abstract

This study examines the teaching of physics practical skills in secondary schools in Sierra Leone. The study develops from the researcher's observations of laboratory work by first-year physics students at Milton Margai Teachers College. Many students could not demonstrate basic science laboratory skills and knowledge required to perform simple physics practicals. Such basic skills and knowledge should have been acquired in the secondary school physics programme in order to succeed in the General Certificate of Education Ordinary (G.C.E. "O") level physics practical examination. This study shows that students fail to acquire ba[illegible]ience laboratory skills because their teachers are unable to conduct physics practicals as they would like to, and this has inevitable consequences for their students' learning.

The study involves three classes (116 students, 20 female and 96 male, between the ages of 16 and 18) and three physics teachers (1 female and 2 male) at three secondary schools in Freetown, Sierra Leone. The students were studying physics in form V in preparation for the G.C.E. "O" level physics practical examination in June 1990. The data include observations of four physics lessons, five physics practical classes, and one laboratory demonstration, as well as nine interviews—three with the teachers and six with students). Data were collected over a two-month period in October and November, 1989. The data are analyzed and discussed in light of the teaching methods and barriers that seem to inhibit students' understanding of scientific concepts.

The study suggests several reasons why students fail to acquire basic scientific laboratory skills and knowledge. The teaching of physics is compartmentalized into "theory" and "practical," and these are taught as separate

and unrelated entities. The formal examination system, which dominates the thinking of teachers and students alike, promotes this division and strongly influences the teaching methods employed in the schools.

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This thesis is dedicated to my deceased father, Jonathan S. Keister.

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CHAPTER 1

INTRODUCTION TO THE STUDY

This study is a qualitative inquiry into the teaching of practical or laboratory skills in secondary schools in Sierra Leone. In addition to this specific focus, for which data were collected in three schools in Freetown, the study also examines the issue of the relationship between direct experiences with physical phenomena in laboratory settings and formal classroom instruction in the theories of physics.

Significant emphasis is placed on practical work in the secondary schools physics programme in Sierra Leone. As in many other countries, personal laboratory experiences are judged to be an important part of the teaching of physics. In English-speaking West Africa, the physics practical is considered so important that it forms part of the formal examination in physics. In Sierra Leone, students in secondary schools begin studying physics as a separate science subject in form IV, after a three-year course in general science that includes biology, chemistry and physics. At the end of form V, the General Certificate of Education Ordinary Level (G.C.E. "O" level) examinations are written in five to nine different subjects. To be awarded a "pass" grade in physics, students must pass both the practical and the theory papers.

In order to pass the practical examination, students require an understanding of basic principles and applications of physics. In addition, students are expected to have developed scientific skills and attitudes that will serve as prerequisites for later learning of more advanced skills of scientific investigation at the university or

teachers' college. To pass the practical paper in the G.C.E. "O" level physics examination, students should possess the following basic scientific skills:

1. Assemble apparatus when instructions and sketches or circuit diagrams are provided.
2. Measure physical quantities within a given level of precision.
3. Identify possible causes of errors in instrument measurements.
4. Record and describe observations accurately.
5. Interpret recorded data from an experiment.
6. Represent data graphically.
7. Make predictions from linear graphs.

Some of the students who pass the G.C.E. "O" level physics go on to study physics for three years at Milton Margai Teachers College (M M T C) to become qualified as physics teachers for the lower forms of secondary schools. In the first year students take an introductory course in physics that involves revision of the G.C.E. "O" level work in physics and basic higher level physics.

Immediately prior to my full-time study for the M.Ed. degree at Queen's University, I taught physics at M M T C for four years (1984-88). During those years I observed that students admitted into the physics programme were unable to perform apparently simple aspects of physics practical work, even though they passed the G.C.E. "O" level physics. The difficulties with practical work demonstrated by many students over a period of several years provided the initial question for this inquiry into the preparation for practical work experienced by students in secondary schools.

Purpose of the Study

The purpose of this study is to document and analyse teachers' and students' activities during physics practicals in order to gain critical insights into the following questions:

1. Why do students not acquire the expected practical skills?
2. How do theory and practice interact in the context of teaching for the practical examination in physics?

Illustration of the Problem

The following examples illustrate some of the difficulties students display during physics practicals. Most students seem unable to connect simple electric circuits, even when instructions for the connections are given and the arrangement of the apparatus is illustrated by means of circuit diagrams. The apparatus to be connected in the circuits may include batteries, rheostat, ammeter, key, resistors, voltmeter, and insulated copper connecting wire. Few students could connect the rheostat properly in order to vary the current flowing through a circuit. The majority of students knew how to connect the ammeter in the circuit but few could do the same for the voltmeter. Most students had difficulty connecting resistors in parallel, although they could connect them in series. The students also had difficulty connecting ammeters and voltmeters correctly in relation to the terminals of the batteries in the circuit.

Students also displayed difficulties in optics, particularly in following instructions accompanied by ray diagrams. Instructions were given on how to set up a plane mirror so that the reflected rays could be traced with optical pins. Instructions were also given on how to trace refracted rays from rectangular glass blocks using optical pins. The ray diagrams showed the direction rays travelled and positions to fix optical pins. Students' inability to trace reflected and refracted rays meant that they could not measure angles of reflection and refraction.

Most students could not determine the appropriate level of accuracy to record values from a meter rule or a micrometer screw gauge. They recorded readings from both instruments with the same number of decimal places, even though the instruments measure at different levels of precision. This inability to record data to the correct degree of accuracy was also illustrated in recording readings from ammeters, voltmeters, and thermometers.

Another example of students' inability in physics practicals involved activities with a simple pendulum. Students are usually required to hang the pendulum from a fixed support, measure a specific length of the pendulum, and give the pendulum a small displacement so that it will oscillate. The students are asked to determine how long it takes for the pendulum to make a given number of oscillations and to find the periodic time for a given length of the pendulum. Most students could not distinguish between the frequency of oscillations and the period of a single oscillation.

A final example prevalent in physics practicals but strongly related to students' mathematical competence is, quite simply, they cannot plot graphs of values obtained from experiments. The difficulty seems related to their inability to determine

the scales to be used on the axes of the graphs. Also, few students could determine the gradient from a graph and make appropriate inferences.

These examples suggest that there is good reason to inquire into the teaching and learning associated with practical work in physics at the secondary school level in Sierra Leone. It is not the purpose of this study to attempt an explanation of how students pass an examination but later lack the practical skills it requires. This study addresses the broader issue of how practical activities are conducted in schools, including the relationship between practical work and instruction in theory, as summarized in these questions:

1. How, if at all, do practical activities contribute to understanding physics?
2. How do practical activities contribute to individuals' development of specific skills for performing laboratory experiments?

Outline of the Study

To collect data relevant to these questions, physics lessons and practicals were observed and interviews were conducted with teachers and students. The interviews and two physics lessons and demonstrations were tape-recorded and extensive field notes were made. The data were provided by three secondary schools in Freetown, Sierra Leone. Participants in the study were three physics teachers and 116 form V science students who were being prepared for the June 1990 physics practical examination.

The data are analysed by listing the reasons teachers gave for conducting physics practicals and comparing them to what the researcher observed during

practicals. The students' impressions about the place of physics practicals in the study of physics and their reasons for doing physics practicals are also analysed. Included in the analysis is an account of how the G.C.E. "O" level physics practical examination affects the methods used to teach physics in secondary schools in Sierra Leone. Excerpts from the interview data with students illustrate how they were unable to apply theory to practice and suggest that practical work does not improve their understanding of physics concepts.

This study shows that the practical portion of the G.C.E. "O" level examination in physics strongly influences the manner in which physics is taught in the schools. The teaching of physics is compartmentalized into "theory" and "practical"; content and concepts are taught in theory classes, while in the laboratory students perform practical activities the results of which are already known to be correct, that is, they verfify known facts in physics. These are the types of practicals that are required for the examination. The practicals students perform do not necessarily follow from the theory that has been taught. Theory is first taught in form IV and the practicals are performed later, in form V, so that teachers will have enough time to finish the theory. Students are drilled several months before the examination on the type of practical work the teachers expect will be asked in the examination. This intensive and specific "coaching" to pass the examination indicates the extreme importance of the examination and also suggests how it becomes possible for students to pass the G.C.E. "O" level physics examination and still exhibit inadequacies in practical skills and the interpretation of laboratory data.

Chapter 2 presents the introduction to the research setting and describes the participating schools and teachers. The section on the introduction to the research

setting describes the examination system, the physics examination, the physics practical examination questions. Chapter 3 examines literature related to the role of practical work in the teaching and learning of physics and describes the research methods. The section on research methods describes the design for data collection, participants in the study and preparation of data for analysis. Chapter 4 presents selections from the data supplied by the teachers and students who participated in the study, and these data are analysed and interpreted in Chapter 5. Conclusions are drawn in Chapter 6, and recommendations are made to physics teachers and students in Sierra Leone. Recommendations for further research are included. Appendix A contains transcriptions of the data collected at School B, including interviews with the teacher and students and observations of lessons before practicals, to give the reader access to the nature of the complete data set. Appendix B contains the question paper for the G.C.E. "O" level physics practical examination in June 1990, to illustrate the types of practical skills tested in this examination.

CHAPTER 2

INTRODUCTION TO THE RESEARCH SETTING AND PARTICIPANTS

This chapter introduces the reader to the context of education in Sierra Leone and to the particular schools and teachers who contributed to the data collection process.

The Examination System in Secondary Education in Sierra Leone

The present system of formal education in Sierra Leone was derived from the British educational system during the colonial period (1772-1961). Movement of students from secondary schools to the university and teachers colleges is determined by public examinations (Johnson, 1981). The public examinations are the General Certificate of Education Ordinary (G.C.E. "O") and the Advanced (G.C.E. "A") levels, which are conducted by the West African Examination Council (W.A.E.C.). Students are evaluated on a nine-point scale at the "O" level standard: 1 indicates distinction, while 7, 8, and 9 indicate failure. At the "A" level standard students are evaluated on a seven-letter scale on which A is excellent, F is failure and S is a subsidiary pass. Students take the G.C.E. "O" level at the end of form V (i.e., 16 to 18 year-olds). Students who obtain passes with distinctions and credits in five or more subjects can either do an additional two years pre-university course ("A" level) in three of the subjects passed at "O" level or enter one of the two university colleges. Students who pass in four subjects at "O" level standard can go to Milton Margai Teachers College where they are trained as teachers for the lower forms (one to three) in the secondary schools.

Students who study physics, chemistry, biology and agriculture up to forms five and six receive instruction on both the theory and practical aspects of the subjects. Some of the objectives of practical work are to enable the students to understand theoretical concepts through laboratory activities, to become familiar with apparatus relevant to the subjects at that level, and to provide training in performing experiments.

The West African Examination Council physics syllabus is the operational syllabus in use in secondary schools that offer physics in their curriculum (General Certificate of Education O and A Level Syllabuses: 1985-88, 1984). The G.C.E. "O" level physics examination conducted by the W.A.E.C. consists of two separate papers. Paper 1 is a practical test lasting two and three-quarter hours and containing three questions, of which candidates are to answer any two to score a total of 60 marks. Each question has two parts: part A involves performing an experiment, which carries 24 marks, while part B consists of three short-answer questions that are related to the experiment and carry 6 marks. (See Appendix B.) Paper 2 lasts for a total of two and one-half hours. Section A contains 60 multiple-choice items lasting one and one-half hours and carrying 60 marks; Section B comprises four essay-type questions, of which candidates must answer any three; this section lasts one hour and also carries 60 marks.

The Physics Practical Examination

Physics practical examinations are usually conducted in the laboratories of schools that prepare students for the G.C.E. "O" level examination. Senior physics teachers and assistants at these schools usually act as invigilators. About two

weeks before the practical examination, the senior physics teacher receives an instruction sheet containing a list of materials and equipment to be assembled for the examination. (See Appendix B.) These materials and equipment may include rectangular glass blocks, converging lenses, optical pins, ammeters, voltmeters (with specifications), meter rules, pendulum bobs, and stopwatches. The senior teacher arranges the materials and equipment in accordance with the instructions given on the instructional sheet.

Students are examined in groups, the size depending on the quantity of materials and equipment available and on the size of the laboratory. Each student receives a question paper and reads through the questions, selecting two questions he wants to answer and then informing the invigilator, who matches every student in the group to a question so that no two students will be working on the same equipment at the same time.

Each question gives detailed instructions and a description of how to proceed with each experiment. In some instances, the questions are accompanied by sketches of how to set up the materials and instruments or circuit diagrams for questions on electricity (see appendix B). Each student works on a separate table on which he will find all the necessary materials and equipment. The questions pose novel problems for students; the skills required to solve these problems should have been developed through the experiences students had in performing physics practicals in schools.

Generally, every question requires plotting graphs and determining values from the graphs.(see appendix B) Students are evaluated on the consistency of their values, on their ability to plot graphs, and on their ability to determine gradients and

make inferences from graphs. Students are not evaluated on their ability to set up the apparatus. It is believed that students can only record values if they are capable of setting up the apparatus. Invigilators are permitted to assist students in areas of procedure if students encounter difficulties in setting up the apparatus but such assistance must be recorded on the students' answer sheet and marks will be deducted for the assistance given.

The Participating Schools and Teachers

This section describes the schools, the laboratories and their facilities, and briefly introduces the three teachers who participated in the study. To preserve anonymity, the schools and teachers are referred to as schools A, B, and C, and teachers A, B, and C respectively. Regular school hours begin in all three schools at 8:30 a.m. and end at 2:30 p.m. with a 30-minute lunch break at 12:00. Each period in the school timetable lasts 40 minutes.

School A

This is a secondary school for girls with a student population of about 800. The curriculum up to form V includes the sciences, arts, humanities, and vocational (typing, shorthand, etc.) subjects. This school has a female administrator as head, and about 75% of the teaching staff are female. Physics in forms IV and V is taught by a female teacher. The school also employs a laboratory technician who studied physics up to form V but has no training as a laboratory technician. He has worked in this school for four years, and his duties involve preparing and arranging

instruments and materials for practical classes and cleaning the laboratory after practicals. He also assists students with their practical work.

School A has a well-built laboratory with some facilities to teach physics up to form VI. The materials and instruments are sufficient to conduct practicals and demonstrations at every level. All the instruments are kept in a preparatory room within the laboratory. However, a few basic materials such as stopwatches, meter rules, rectangular glass blocks, triangular glass prisms, ammeters, voltmeters, low-value standard resistors and rheostats are limited in quantity. The school has a separate building with laboratories for chemistry, biology, and physics. Physics classes are held in the physics laboratory which has three long benches with gas taps, a long concrete bench along the side with four water taps, a demonstration bench with water and gas taps, a blackboard, and enough stools for every student. Three students can conveniently work on each of the benches. The laboratory is well ventilated, tiled and clean, with a bright and spacious appearance.

Practical classes for form V are held in the afternoons after lunch break during a double period (80 minutes). Before practicals begin, the teacher gives a detail explanation of the procedures, theory, measurements, calculations and precautions that should be observed in carrying out the work. There were 20 students in form V science and each one worked alone with a set of apparatus. More than one experiment is set up during each practical period, to ensure that each student works on an experiment each time. The two sets of experiments scheduled for the two weeks period involved using the simple pendulum to determine the acceleration due to gravity and measuring the specific heat capacity of a metal using the mixture method. These two sets of practicals were performed over a period of two weeks.

School B

This school has a student population of about 1000 males. Only boys are admitted to forms I through V, and a few female students are admitted into form VI. Some female students prefer to study form VI science subjects in this school, rather than at School A, because of the mixed classes, the presence of university lecturers, and the good G.C.E. "A" level examination results in science in recent years. The curriculum consists of traditional academic subjects and some technical subjects, with much emphasis on science. About 25% of the students who take the G.C.E. "O" level examination do well in science subjects and hence go on to form VI and subsequently enter university. The administrative head is male, and so are most of the teachers. Because there is a shortage of physics and mathematics teachers, university lecturers help with these two subjects in form VI by working as part-time teachers. Three people teach physics in forms I to V and they also teach mathematics.

This school also has a separate building for its science laboratories. In the physics laboratory, adequate facilities were provided to teach physics and the other science subjects up to form VI when the laboratories were built in the 1960s. Facilities in the physics laboratory have deteriorated to the extent that there is little equipment in stock in the preparatory room. Basic equipment to do practicals and demonstrations is severely restricted, and the physics laboratory is almost bare. In the laboratory are two long wooden tables with gas taps and electrical plugs along the sides, two long concrete tables fitted with water taps along the walls, a teacher's demonstration table fitted with gas and water taps, a blackboard, and empty

cupboards. The laboratory is lit by windows along the sides, but there was not a single stool for teacher and students to sit on.

Physics classes are held in a classroom adjoining the building housing the laboratories. The classroom is spacious, well-ventilated, and bright on a sunny day. On a cloudy day the classroom is dark even if there is electricity because the electrical fittings on the ceiling and walls have been removed. Only electric cables, taped to provide insulation, remain in the places of the fittings. A blackboard and demonstration table are at the front of the classroom. The classroom also contains 10 wooden-topped concrete tables fixed to the concrete floor. Each table is designed for two students to write, but the tables could also be used for practical activities. There were few stools for the students to sit on; most students were leaning against the walls so they could copy from the blackboard. The few students with stools clustered around the demonstration table in order to hear what the teacher was saying. During demonstrations, students stood on the tables to see what the teacher was doing.

There were more than 40 students in form V science. Physics practicals for form V were conducted during a double period (80 minutes) in the morning. Students worked in groups of five because there was not enough equipment to set up more than one set of practicals. The teacher usually asked students to come with instruments so that there would be enough for every group. Two practicals were scheduled for a two-week period; one was performed by the students and the other was done as a demonstration by the teacher. The experiment to determine the refractive index of glass was performed by the students, while the teacher demonstrated how to measure minimum deviation of a triangular glass prism.

School C

School C is also a school for boys, with an enrolment of about 600 students. Female students are admitted to do sixth form courses in arts (English, French, geography and history) and economics. The curriculum consists of grammar school type subjects with emphasis on the art subjects. In recent years the G.C.E "O" level examination results in physics have been very good. This has caused an increase in the number of students doing physics in form V. The adminstrative head is male, and so are about 60% of the teachers. There is a shortage of physics and mathematics teachers, with only two physics teachers in the school.

The physics laboratory is not as spacious as the ones in schools A and B. It contains three wooden tables at the centre and two concrete side tables. The side cupboards house some instruments that have become obsolete, yet they are well kept. The preparatory room holds some additional equipment. There are not enough instruments to teach physics practicals in form V, but the equipment that is available is well cared for. There is no laboratory assistant, so the physics teacher sets up all the practicals and the students help him to clean up after practicals.

Physics classes are held twice a week after the regular school hours. These classes were held on Friday afternoons from 2:30 to 4:00 p.m. and on Saturday from 12:00 to 2:00 p.m. These hours are for the convenience of the physics teacher, who is pursuing another course. Form IV and form V physics classes are combined and taught as one class, and students from other schools also attend these classes. Of the 50 students in the class, 25 were in form V, 15 were in form IV, and 10 were students from other schools. Students worked in groups of four during practicals.

Teacher A

Teacher A is professionally trained and holds a Bachelor of Science degree in physics and mathematics from a British university. Her 10 years of experience teaching physics include three years at school A. Teacher A teaches physics in forms IV and V and mathematics in form V. She is an active member of the Sierra Leone Science Teachers Association. Teacher A was observed during two practical classes and contributed one recorded interview to this study.

Teacher B

Teacher B holds a Bachelor of Science degree in education (in physics and mathematics) from the University of Sierra Leone. He is relatively new to the profession, with three years of teaching experience. He teaches physics in forms IV and V and mathematics in form IV. Teacher B conducted two revision and demonstration lessons which were recorded verbatim. He supervised a practical and conducted a demonstration that would have been done as a practical if the required equipment had been available. Teacher B also took part in an interview which was recorded.

Teacher C

Teacher C holds a Bachelor of Science degree in physics and chemistry and a Diploma in Education from the University of Sierra Leone. He has been teaching physics for seven years at School C. He teaches physics in forms IV and V but teaches both classes as one class. Teacher C supervised two practicals and took part in one interview for this study.

CHAPTER 3

LITERATURE REVIEW AND RESEARCH METHODS

Review of Literature on Laboratory Practical Activities

Even though the laboratory has been regarded as having a major role to play in helping students understand science, the results have remained disappointing. At one level, covering the curriculum consistently takes priority over first-hand practical experiences when teachers make inevitable choices about the use of limited time. At a second level, there is confusion about the role that practical work can and should play in helping students to understand scientific concepts. This literature review examines recent research on the place of laboratory practical work in the teaching of science, with special attention to the teaching of physics.

Researchers in the area of science education have proposed various explanations for why students have difficulties with science in general. Some of these theories correspond with students' own ideas about why they have difficulty with physics practicals. When Brook and Driver (1984) investigated 308 secondary students' understanding of energy, they asked students to use pre-existing ideas to explain selected phenomena in energy. The results indicated that students' pre-existing ideas do not always explain phenomena in science adequately, and sometimes lead students to make wrong associations. In another study, Brook, Briggs, Bell, and Driver (1984) investigated students of varying abilities and science backgrounds on their understanding of heat (conduction). The students based their explanations of conduction of heat on accepted ideas rather than on a scientific

explanation. They did not have consistent frameworks to draw on to explain events. This study suggested that when students are presented with ideas in science lessons, they tend to make them fit into their intuitive ideas. These studies signal the importance of attention by teachers to their students' existing ideas about a concept, particularly in the laboratory practical context in which students interact directly with phenomena with only occasional contact and interaction with the teacher.

Among the barriers identified by Colton (1982, p. 38) as influencing students' understanding of science and mathematics is the students' literal interpretation of schematic diagrams.

> Most science and math teachers rely heavily on diagrams to explain their work, but these are often not understood and are frequently misleading; they probably fall into the category of barriers which we have labelled as pedagogenic-those which are the result of teaching, not necessarily of poor teaching, but teaching that is unaware, lacking in a conscious effort to understand and forestall the difficulties of the learner.

Flexer (1982) investigated barriers that influence students' difficulties in understanding science. In reference to the circuit and ray diagrams in electricity and optics, Flexer holds that there are some concepts, objects, instruments and phenomena in science that can be represented diagrammatically. These representations are meant to help students visualise the concepts or positions of the instruments. Students reconstruct their knowledge to fit more closely with the representation than with what is being represented, and thus such representations may be unintentionally misleading. When students have such difficulty, they have a problem of confusing reality with representation.

Often, science instructions present views of phenomena that conflict with concepts students already have about science. Driver and Easley (1978) and Driver and Erickson (1983) have reviewed studies in this area. Some science educators (Champagne et al., 1985a; Driver, 1983; Driver & Oldham, 1986; Hawkins, 1983; Hewson & Hewson, 1983; Hewson & Hewson, 1984; Nussbaum & Novick, 1982) argue that science instructions should be presented so that students' preconceptions could be identified and improved. Students' preconceptions in science are sometimes valid, and they use them to operate in their daily environment. It is plausible that students may fail to acquire practical skills from laboratory activities and fail to relate activities to theories when their practical experiences conflict with conceptions already held.

Whether one views science teaching as replacing prior (incorrect) concepts or as building on students' preconceptions about scientific phenomena, it is commonly assumed that practical activities play an important role in science teaching. Barnes (1976) argues that students are faced with a dichotomy between school knowledge, the information presented by the school which is largely learned by rote, and action knowledge, which forms the basis of students' understanding of everyday phenomena. White (1979) underscores the need for laboratory practicals in the teaching of science, arguing that practicals link science with daily life and provide experiences upon which to frame new concepts. Champagne et al. (1985b) support practicals because of the extent to which such experiences can relate aspects of the problem to relevant prior experience (p. 85). Hawkins (1974) also supports students' activities in the laboratory but cautions that such activities should be structured in order to make scientific concepts explicit to the students. Taking a

more critical perspective, Driver (1983) suggests that it is important to regard the role of practical activities as an assumption. "We have placed faith in discovery; that by doing experiments pupils will better understand ideas. This may have a part to play, but experience alone is not enough." She goes on to say:

> It is common to see science lessons which end with the clearing up after the practical work is finished. The time for the important discussion of how the experiences gained relate to the new ideas is missed. Activity by itself is not enough. It is the sense that is made of it that matters. Teaching strategies are needed which help pupils think and talk about the significance of their experiences and, most important, time for teachers to talk through pupils' experiences with them. (p. 49)

The data presented in this study testify to the insightful nature of this commentary.

Even though there is widespread agreement (at the level of espoused theory) that practical activities in the laboratory should improve students' understanding of scientific concepts, there is little evidence (at the level of action) that science teachers organize practical work in ways that enable students to acquire the desired understanding from laboratory practicals. Few studies have addressed the need to develop, and to integrate into the existing context of teaching, strategies that will enhance students' understanding of scientific concepts through laboratory practicals.

Raghubir (1979) speaks of the need to develop a teaching methodology that will improve students' understanding in laboratory practicals. He expresses the opinion that teachers do not give students the opportunity to do practicals that will

explain concepts but instead get students to do practicals that verify facts already known. One result is that students fail to make effective use of laboratory work.

> Teachers tell students too much; they deprive them of the opportunity to learn for themselves. In the laboratory, for example, they are likely to tell them just about everything—how to assemble an apparatus, how to design an experiment, and what outcome to expect. Of course, they think they do this for a good reason—to save time and to "save the experiment." However, it seems that in spite of their enthusiasm, planning, and zeal, the students frequently leave the laboratory having performed the exercise well, but with low retention of information and even lower comprehension of the significance of the information. (p. 13)

Even earlier, Thomas (1972) and Rasmussen (1970) saw the need to develop teaching methodology that could be used in teaching practicals. Thomas supports the use of laboratory practicals but maintains that the question of how best the laboratory can be used as part of an instructional programme remains to be answered. In giving his conditional support to the use of the laboratory to study science (biology), Rasmussen suggests that "if the biology laboratory is to be used to advance understanding of how science operates, the instructor will have to identify that behavior he is trying to promote and design objectives and activities that will achieve these ends" (p. 293).

Millar (1989) advocates that science should be taught as process-based activities in schools. The activities he classifies as process-based are observing, classifying, interpreting, predicting, evaluating, inferring and hypothesizing. He believes that the essence of science in any school's curriculum is to develop these

processes in their students. He suggests that these process objectives should be set alongside those relating to content and concepts as though they are each part of one entity. Millar holds that teachers should focus on the development of these processes while teaching science. He claims that "by making these processes the focus of instruction (either explicitly or implicitly), pupils will develop very general skills which they can apply to new problems in new areas, either within science or beyond" (p. 51).

Woolnough (1989) also proposes a holistic method of teaching science in schools as against the practice of reducing science teaching to component parts. Physics teaching in Sierra Leone can be viewed as compartmentalized into theory for content and concepts and practical work for the verification of known facts. Woolnough anticipates the extent to which the method of assessing students in physics in Sierra Leone influences the teaching method teachers adopt. "What is less often recognized is that the form of the assessment procedures can, by defining what is regarded as important, fundamentally affect the way that a subject is taught" (p. 123).

Renner (1982) contrasts two theories of learning, theories that he distinguishes as "A" and "B." Theory A explains how students learn information received from teachers. The teaching procedures used in Theory A involve the teacher informing students, students verifying what they have received from their teachers by performing experiments with known outcomes, and students practicing what they have acquired by attempting questions and problems from their textbook. In Theory B, students are exposed to experiences that are to be acquired and from which they will create what is to be learned. The procedures involved in Theory B are exposing

students to experiences, introducing the language (terms) to describe the observed phenomena, and organizing the new idea with existing knowledge to expand that knowledge and the newly acquired knowledge. Efforts by Schneider and Renner (1980) to compare instruction organized in terms of these two approaches to learning showed positive results for Theory B, but there is no evidence that their work has spread beyond the schools in which it was developed. It is important to note that there is a strong similarity between Renner's Theory B approach to learning and Driver's recommendations for the importance of making sense of laboratory activities.

Some of the studies in this review point out that there exist factors that inhibit students' understanding, explanation and application of scientific facts and concepts. A few studies also point out that through laboratory practicals these inhibiting factors could be reduced, if not eliminated, and hence improve students' understanding of scientific facts and concepts. The studies reviewed make a strong case for the use of laboratory practicals to improve students' understanding, but that case rests heavily on specific teaching strategies that are not commonly used.

As some educators caution, the methods used to teach practicals may not accomplish the desired effects. It has been observed that teachers tend not to discuss students' results and observations after practicals, that teachers often tell students what to do and look for during practicals, and that students participate in limited ways in the process of investigation. Alternative strategies for conducting laboratory work have been proposed, but it is also noted that the method of assessing students can influence the methods teachers use in the practical context.

Overall, the studies reviewed indicate the importance in every school context—national, provincial, and local—of inviting science teachers to examine the role of laboratory work in their teaching of a particular science subject such as physics. It is clear that the goals for laboratory practical work are very important ones, just as it is clear that these goals are not automatically achieved by having students manipulate equipment in a science laboratory.

Research Methods

The section explains how entrance was gained into the schools and how the researcher contacted the teachers. Also included in the section are descriptions of the data collection design, the study's participants and the plans for data analysis.

Contacting Principals and Teachers

Obtaining permission from the principals and establishing a conducive working relationship between the physics teachers and the researcher was crucial to the successful collection of data for this study. Two separate informal meetings were held with the physics teachers of each school during lunch breaks. This was to ensure that these teachers would be free from teaching and that no distraction be caused by the presence of the researcher in the schools during teaching sessions. During the first meetings, the researcher discussed with each teacher what the study was about and what it involved. Apart from the discussion, each teacher received a copy of the study's proposal to read through before the second meetings. The purpose of the first meetings was to provide the teachers with a basic understanding of the study; the second meetings would provide opportunities to ask questions after

reading the proposal, before they gave their consent to participate. School-based research that involves observing and interviewing teachers and students is not common in Sierra Leone. The researcher's apprehension after the first meeting with each teacher was that they might feel that the study was intended to investigate their teaching methods.

Thus it was not surprising that two of the three teachers found it difficult to believe that the research was not intended to question their methods in the laboratory. The researcher explained to them that the study would not only investigate their methods but would also report on how students do physics practicals. In response to the teachers' concerns, it was agreed that only their practicals would be observed. The third teacher agreed to let the researcher sit in on his physics classes in addition to observing his practicals. The three teachers agreed to participate in the research and each signed a consent form.

Three separate informal meetings were held with the principals of the schools. The researcher used the informal method of meeting the principals because, as Goetz and Lecompte (1984) believe, "Generally, informal, face-to-face contacts are more effective. People, are more likely to respond positively to direct, interpersonal appeal, and informal networks are often trusted more than official channels" (p. 88). Also, the researcher had helped in teaching physics in form VI in two of the schools and had also loaned apparatus for physics practicals to the third school. The principals gave their permission to work in their schools and later introduced the researcher to the physics teachers who had already given their consent to participate in the study. The strategy of first making contact with participating teachers, then the principals, and finally back to the participating teachers was

intended to build trust and friendship between the researcher and the participating teachers. It was also intended to reduce the feeling that the teachers were participating because of directives from the principals.

Design of the Data Collection

Data were collected in three secondary schools in Freetown over a period of eight weeks. The first two weeks were used in making contacts with the principals and participating teacher in each school. The remaining six weeks were used to collect data, two weeks in each school. In each school the teacher identified two students who were interviewed after physics practicals. While observing a class perform practicals, attention was focussed on one of the identified students either when working alone or in group. The two students were observed during two separate practicals.

The individual focus strategy was used in order to observe the specific nature of behaviour exhibited by students, including manipulation of apparatus, asking questions of particular interest, and the extent to which all students in a group shared tasks or permitted one or a few to direct the group's activities (Shymansky & Penick, 1979, p. 198). As students were performing practicals, the researcher observed how teachers asked questions, gave directions, transmitted information, provided feedback and observed students at work (Shymansky & Penick, 1979, p. 179).

After the practicals two students were interviewed separately in each school. The students that the researcher focussed his observations on were the ones that were interviewed after practical classes. These interviews were to corroborate the researcher's observations during the practicals and to record students' impressions

about the practicals they do in schools. The interviews further tried to determine the extent to which students understood what they were doing and to talk about the difficulties encountered and how they approached them. Below are some of the questions the researcher asked the students.

1. What was the practical about?
2. What were you required to investigate in this practical?
3. Which aspect(s) of this practical do you have a problem with?
4. How did you overcome the problems?
5. How did you get your numerical values?
6. Could you think of possible areas that will produce mistakes in getting your values?
7. How are you going to analyse the values that you have recorded?
8. Will you have problems in analysing your values?
9. Why do you have to do physics practicals?
10. How would you summarize what you have learned from this practical?

After observing students doing practicals and interviewing them after the practicals, the participating teachers were then interviewed. The interviews provided information about the teachers (qualifications, teaching experience, teaching schedule), about how students are selected to study physics in form V, about why teachers taught physics practicals the way they do, about how public examinations influence their teaching methods, and about their general views on physics teaching in Sierra Leone. Questions put directly to the teachers individually included the following:

1. How are students selected to study physics?
2. Why do students do physics practicals?
3. How often do students do practicals?
4. Which aspects of physics practicals do students have difficulty with?
5. How do you conduct physics practicals, and what is your rationale for using such method?
6. If there were no public examination, would you conduct physics practicals differently?
7. How do students relate theory to practice in physics, and what part do practicals play in this process?
8. What type of practicals do students perform?
9. How would you describe the G.C.E. "O" level physics practical examination?
10. If you were asked to prepare the G.C.E. "O" level physics examination, what types of questions would you set?

Participants in the Study

Participants for this study were three physics teachers (a female and two male) and 116 students aged 16 to 18 years from three different secondary schools in Freetown. The total of 116 students included 20 girls from school A, 46 boys from school B and 50 from school C. These students are in form V science and are being prepared for the G.C.E. "O" level physics practical examination in June 1990.

Preparation of Data for Analysis

Extensive field notes were taken in order to describe the laboratories and students' and teachers' activities while working in the laboratories (Tamir, 1977; Goetz, 1976a, 1976b; Olson & Russell, 1984). Interviews with teachers and students, revision lessons and demonstrations prior to practicals were recorded verbatim using a tape recorder. Most recordings were transcribed; the complete interviews for School B are presented in Appendix A. The interviews recorded included two from school A (one from each student), four from school B (two each from two students), and three from the teachers (one from each teacher). The interviews of students from school C were not transcribed and reported because they contained little more than one or two word responses that did not add anything new or different from what the students of the other schools said. The two revision lessons and demonstrations recorded verbatim were those of the teacher in school B (See Appendix A).

Analysis of Data

To fully familiarize myself with the data, I listened three times to each of the recordings of interviews and observed lessons and demonstration for each school. The data were then transcribed by hand and typed into separate files on a computer. The anonymity of the participating schools, teachers and students were preserved by using codes for each speaker. The printed transcripts were then read a number of times to identify major themes and supporting illustrations. Identified categories in the data were highlighted using different coloured makers for each category throughout the printed matter. The data for each school were categorized into

laboratory facilities and apparatus; instructional method; teachers' and students' activities before, during, and after practical work; students' narrations about difficulties encountered during practical work; students' views about the type of practical work they do at school; students' views about the methods teachers employed to teach physics practicals; and teachers' views concerning physics practicals in relation to understanding physics concepts and how the G.C.E. "O" level physics practical examination influences their teaching methods. Subsidary files for the above categories were created, and portions belonging to a particular category for each school were transferred to those files.

The above categories were later reduced to four categories that could tell the story of the study in a logical sequence.

1. Teachers' Goals for Practical Work
2. How Teachers Conduct Practical Work
3. Pressures and Constraints on Practical Work
4. Consequences for Students

Sorting data into these categories permits comparisons of themes and identification of patterns to be related to the conceptual framework drawn from the literature reviewed. Renner's (1982) study is particularly helpful in describing consequences of the major teaching patterns identified.

CHAPTER 4

PHYSICS PRACTICAL WORK IN THREE SCHOOLS IN SIERRA LEONE

This chapter reports excerpts from data collected at each of the three schools in Freetown in October and November, 1989. The purpose of this presentation of data is to indicate in some detail the nature of laboratory practical work performed in each school, along with the perspectives of the teachers and a few of the students. The data include lessons before practical work, teachers' and students' activities during practicals, and interviews with students and teachers after practicals. In the presentation of data, the letters A, B, and C designate, respectively, the teachers at schools A, B, and C. The letters JK indicate the statements by the investigator, and various student comments are designated by S.

Physics Teaching at School A

In school A two sets of practicals were set up for 20 female students; these enabled each student to work independently. The two activities were determination of acceleration due to gravity (using the simple pendulum) and measurement of the specific heat capacity of a metal. The practical on measurement of specific heat capacity was a new set added to the existing set involving the simple pendulum. Teacher A spent the first 10 minutes explaining procedures and precautions to be observed in performing practicals on measurement of the specific heat capacity of a metal. Below is an excerpt from the explanation before the practical. The teacher's statements strongly suggest a *verification* perspective on the role of practical work; theory has already been learned and understood, and the personal

activities will verify that learning, with appropriate consideration for experimental error.

Excerpt from a Lesson introducing Practical Work

A: The outer containers are aluminum but there are calorimeters in them. Some are copper ones with copper calorimeters in them. A calorimeter is just a metal cup. Some of you have copper and the others have aluminum calorimeters. In between the calorimeter and the outer container, the space is filled with some poor conductor material. This space is supposed to be well stocked with poor conductor. Some of you have cotton wool, others have shredded paper, and we filled it up with toilet tissues so that little or no heat is lost through the calorimeter to the outer container. Then you have the stirrer with which you stir the liquid after you put the metal in the calorimeter. Provision is also made for the thermometer.

So according to the theory we have covered, we are going to use the fact that the heat lost by the metal to water in the calorimeter is equal to the heat gain by the water. We are going to heat the metal in the pot containing water. The temperature of boiling water we measure with a thermometer. So we will assume that the temperature of the metal is the same as the temperature of the hot water. As I have told you before, the transferring of the metal from the hot water to the calorimeter is where you have errors coming in. This has to be done very quickly. Also you do not have to drop the metal into the calorimeter because water will splash out from the calorimeter, thereby reducing the mass of the water

that has been recorded. So it has to be put gently into the calorimeter. Heat will be lost to the atmosphere when transferring the solid from the hot water into the calorimeter. You have to keep stirring after putting the solid into the calorimeter until a steady temperature is reached which is the final temperature. With what I have told you, you should be able to carry out the experiment.

There were no laboratory manuals or hand-outs for practicals from which students could follow instructions. The students used their text books to do practicals. During practicals Teacher A went round observing students at work and explaining points that may not have been made explicit during regular physics classes. The assistance to students ranged from how to set up practicals to the use of measuring instruments. The laboratory assistant also helped students set up the materials and instruments. No interaction between students was observed.

After the practical work, Teacher A identified two students whom the researcher interviewed separately in order to explore the extent to which they understood what they were doing and to talk about their difficulties. Included here is an interview with the student who worked on the measurement of specific heat of metal. The student is generally clear and straightforward, and is definitely aware of the relationship of practical activity to the examination at the end of form V. The student reports limited and delayed communication with her teacher, and specifically describes the purpose of the work as a check on whether or not the theory learned earlier has been understood. Reported weaknesses involve manipulation of equipment and subsequent analysis of data.

Interview with a Student after Practical Work

JK: What was the practical about?

S: It was to determine the specific latent heat by using the calorimeter.

JK: Did you understand what you were doing?

S: Yes, I understood the procedure.

JK: Did you read about the practical before coming to the laboratory?

S: Our teacher gave us the notes about the procedure and precautions before coming to the laboratory.

JK: You did not read about the practical yourself?

S: No, the teacher gave us the notes first before we had the practical.

JK: Which aspects of the practical did you have problems with?

S: I did not know how to measure the temperature at first.

JK: What do you mean by *I did not know how to measure the temperature*?

S: That was my first time I measured the temperature of a liquid, so I did not know how to go about it.

JK: How did you overcome that problem?

S: The teacher explained to me how to do it.

JK: How did you read off the values from the thermometer?

S: The thin line in the thermometer, when you see it go up when stirring the calorimeter and stop at a point for a while, that gives you the value for the temperature.

JK: What do you call the *thin line in the thermometer* that moves?

S: [No response]

JK: What do you call the liquid in the thermometer?

S: [No response]

JK: It is called mercury. Could you think of areas that will produce error in your practical?

S: Yes. If you take the solid out of the hot water you should do it carefully so that when you put it into the calorimeter it does not splash water or else you will not get an accurate reading and then you should take the solid from the hot water as fast as possible so that it will not lose heat to the atmosphere.

JK: How do you hope to analyse your readings?

S: After you have got the mass of the solid, mass of the calorimeter, mass of calorimeter and water, the initial temperature of the water in the calorimeter and the temperature of the mixture in the calorimeter, you subtract T1 from T2 so that you will get the temperature of the calorimeter.

JK: What are T1 and T2?

S: T1 is the initial temperature of the water in the calorimeter. T2 is the final temperature of the water in the calorimeter.

JK: What were you investigating during the practical?

S: [No response]

JK: Were you investigating that the heat given out by a hot body is equal to heat gained by another body?

S: Yes.

JK: Which body gave out heat and which one is receiving heat?

S: The hot water is giving heat to the solid.

JK: What about the solid and the calorimeter?

S: The solid is giving out heat to the water and calorimeter.

JK: So how will you analyse your readings?

S: [No response]

JK: Why do you have to do physics practicals?

S: We do practicals to know if we understand the theory that we have been reading. We also do practicals to prepare for the G.C.E. "O" level physics practical examination. Most of the marks in the examination are gained from the practical. If you fail the practical, you will fail the whole examination no matter how well you answer the theory and the objective questions.

JK: Do you think that the practicals you have been doing will prepare you adequately for the examination?

S: Well yes, although I don't understand some of the practicals very well but some I do understand.

JK: What problems do you generally have with practicals?

S: I have problems with understanding instructions, following procedure, setting up of apparatus and finding gradients from graphs.

JK: Which aspect are you having difficulty with?

S: I don't understand how to go about it to find the gradient.

JK: Have you discussed it with your teacher?

S: No, we have not yet discussed it.

JK: Why have you not discussed it?

S: Because we have not yet submitted our practical exercise books for marking.

JK: How many practicals have you done so far?

S: We have done five practicals but the teacher has not marked them yet.

JK: What would you say the teaching is like?

S: The teacher sometimes gives us notes about the practicals we should do. Some other times she asked us to read about them and find out how to do them.

JK: Do you have a practical manual?

S: What is that?

JK: It is the book that you use to do practicals, it has instructions and procedures of how to do an experiment.

S: No.

JK: Where do you get instructions to do practicals?

S: Some of the practicals are in our physics texts but we do not have a particular text for practicals. We use our text to read for practicals.

JK: But your text does not give instructions for practicals?

S: The text gives instructions but they are not too clear to understand.

JK: Do you understand when your teacher teaches and conducts practicals?

S: We do not understand how to go about with some of the practicals. She does not explain to us; she says that we should read on our own and to do the practicals which are difficult to follow without assistance.

JK: How often do you do practicals?

S: Once a week.

JK: When did you start doing practicals?

S: When I came to form V. In form IV we did theory only. If we had done practicals in form IV, it would have helped us to understand the theory better and to be able to do well on the practical [exam].

JK: Do you know why your teacher did not do practicals in form IV?

S: She used to tell us that we have a lot of theory to cover for the G.C.E. "O" level examination. I think it is the pattern to do practicals in form V.

JK: After your practicals, do you discuss your readings with the teacher?

S: No, since we started practicals she has not yet looked at them. We don't know whether the answers are correct or not. She does not look at them.

The school day was over by the time the interviews with students were finished. An appointment for an interview with Teacher A was fixed for two days after the practical work. This interview was conducted to explore the teacher's views about physics practicals and the teaching methods used to conduct practicals in physics. Problems prevalent in the teaching of physics in general in Sierra Leone were also discussed during the interview. Below is an excerpt from the interview with Teacher A. When asked how she would conduct practicals if there were no examination, Teacher A indicates that practical work should follow immediately after presentation of theory; she also indicates that laboratory activities are helpful to learning theory.

This excerpt includes a passage in which Teacher A very clearly describes learning as something that happens after teaching, when the student is at home with books and notes. She assumes that notes given to students will convey adequately the concepts they describe if the student devotes proper time to studying the notes. Teacher A also discusses the negative attitude that students have toward physics, which they tend to see as difficult and impractical.

Excerpts from an Interview with Teacher A

JK: How are students selected to study physics?

A: Usually after their third form they are streamed, invariably according to their performance in the different subjects. Those who are mathematically good and seem to have the aptitude for the sciences go into the science stream where it is automatic they have to do physics. The others are streamed into the arts, economics, and commercial. So it is automatic they do physics in form IV if they have been streamed into the science stream.

JK: Why do students do physics practicals?

A: To aid the theory, to give a better understanding of the theoretical aspect of the subject.

JK: How often do students do practicals?

A: In the fifth form it is once a week. We try at least once a week. In form IV usually they don't have practical for the first one or two terms, but when they start doing heat and other topics which have practicals that can be done in the school they start the practicals. So towards the

end of the fourth year and then also at the fifth form until the G.C.E. physics practical examination.

JK: What difficulties would you say students have when doing practicals?

A: There are certain areas where they find the theory difficult and consequently the practicals. I find that with experiments on moments. The students may be able to perform the procedure, go through the procedure, but then the essence of the experiment is not well understood. For electrical experiments, we used to have problems because of availability of apparatus but now that we have ours it is not as bad as before. But connecting circuits take a long time to do. And again putting the theory to the practicals in electricity. But otherwise I don't think we have any particular areas that give the students so much problems.

JK: How do you conduct physics practicals and what is your rationale for adopting such a method?

A: Since the students are not usually too many in the science stream, I have each student working on her own so they do it individually. And because of lack of apparatus they do it on a rotational basis so that I have to set a series of practicals. Usually, I set four practicals at a time and each student should do the set of four before going to the next. So we just rotate the apparatus around until the first set is covered. I tried to keep the experiments on mechanics together, the experiments on heat together, etc. We have a shortage of stop clocks and a shortage

of thermometers, and the experiments that can be set are limited by the apparatus available. I cannot set more than four simple pendulum experiments, so if I want each student to work on a practical herself I have to set more than one set of experiment.

JK: In the last physics practical, I observed that students do not have physics practical manuals?

A: Before the practicals I send them the particular experiment that we will be performing. They are suppose to read the section pertaining to the experiment in their textbook and write out their procedures and whatever is relevant to the experiment before coming to the lab. Whatever I want them to do after performing the practicals in their write-ups, I give to them. So they have all that before coming to the lab. The problem I am having is that a lot of them neglect the work that is given before the practicals, so much so that they are lost when they come to do the work. But technically they have all that is required for the practicals before hand.

JK: Don't you think that if you monitor the students' work by asking them questions pertaining to the practical to be performed, it will make them read the relevant portions for the work?

A: Well, it is a question of time. We are starting in the fifth form. The students have the G.C.E. "O" level physics practical examination to take in May. So I am torn between throwing them out of the class if they are not prepared for the lesson and the amount of practicals we have to cover within that short space of time. Even though once in a while I throw

them out to keep them in line, it is difficult. Otherwise you will find that there are some students who will not do any of the practicals and they end up with a problem when the exams come.

JK: If there were no public examination how would you conduct physics practicals?

A: We are limited in apparatus but I would like to conduct practicals for each section pertaining to the theory, so that after I teach a particular topic we are able to go to the lab to do the experiments which are connected to that particular bit of theory. If one had a free hand time wise as well,we should be able to do it. But we are only starting the "O" level syllabus effectively in form IV. That means that we have about a year and a few months and that is not enough. We have to select those experiments we feel will likely come in the exams, concentrate on those, and just do one or two that are supposed to assist the theory the students learn.

JK: How do students relate theory to practice and what role do practicals play in this process?

A: I try my very best to get them to be able to relate theory to practice. This is why I want them to read beforehand, but there is a dislike for the subject. Therefore I think they spend very little time on the subject. The students are never prepared for the practicals; therefore they don't appreciate what you want to get at. If we do moments, for example, and give them three or four readings to find the unknown mass of an object, they cannot relate the calculations in the theory to the ones they have to

do after they have done the experiment. The reality of actually being able to perform the act in the lab does not really get to them; otherwise I won't have problems getting them to write up their labs.

JK: During the practical class, I observed that a student who seemed to know what she was doing could not tell the difference between the time taken to do a number of oscillations and periodic time.

A: Well she had difficulty because she had not read, she had not studied, she had not gone back to her books, because these are things that we have discussed at length and I don't think there is any more that I can give in that respect. If I teach a topic in class and students don't go home to read their text books, read their notes, there is nothing I can do. It means that they are never going to learn. The next time we move to another topic they forget what I have taught them. The teaching is one thing but the learning is another. If they are not prepared to spend the time with their work, then it is one of the problems that I am having.

JK: Do you usually conduct a post-lab discussion with your students?

A: Yes, we go through them in class, invariably after I have seen their practical work. Also I encourage them to come one at a time to me in the staff room with their problems so that I can assist them individually. As I said earlier, the class this year is big, about 25 students so it is not as easy as before. In the past years I discussed each practical individually with each student, but now it is only those who are willing to discuss their work with me that I will give time to.

JK: How would you describe the G.C.E. "O" level physics practical examination?

A: Well, with the limitations [of time and apparatus] the Exams Council cannot do much. A lot of schools really have problems with their apparatus, even finding those which are asked for in the examination. Teachers have to run around to the university and other schools trying to borrow apparatus. So I don't know what W.A.E.C. is going to do about it. The unavailability of the apparatus has limited the effectiveness of the physics practical examination. Right now I know there are a lot of schools where there are no practical lessons before the exams. Towards the exams they get the students to do one or two practicals they feel might come in the exams and that is it.

JK: How do teachers select the few practicals they think will be asked in the exams?

A: Over a period of a number of years we tend to see what the trend is. So teachers can predict what the practical examination will be like.

JK: If you were asked to prepare the G.C.E. "O" level physics examination, what type of questions will you set?

A: The paper now consists of a lot of objective questions, which is good because it tests the basic facts the students know. But they are not testing enough of the application of the subject. You study physics, then of what use is it? In the present syllabus, the exams do not actually examine the applications of physics as a subject. We are just teaching the students a lot of theory but they don't know what to do with the theory.

So perhaps if I have my way I will include a few more questions on the practical application of the subject so that students appreciate the subject as something practical. Right now it is one of the most disliked subjects in schools.

JK: What is the general attitude of students to physics?

A: Very negative. Very negative.

JK: Why?

A: I think there is a misconception that it is one of the most difficult subjects. A conception, I think, not a misconception, that it is one of the most difficult subjects, so they have a negative attitude even before they start learning the subject. In the initial stages of studying physics, it is a bit dry. I have to admit myself that it is dry. When you start topics like units, mechanics, etc., I think that tends to put them off. And yet it is essential that those topics be taught, because if you don't know how to measure you will not be able to do anything in the subject.

JK: Do you see a change of attitude towards the subject in the future?

A: Nobody is doing anything about it so I don't think there will be any change in the near future. At the university the attitude towards the subject is negative. There is no effort been made by the [physics] department to encourage anybody to go into the department. From that level it filters down. We are not going to have graduates in physics. We are not going to have good teachers in physics, teachers that have actually studied the subject, so that in the long run it has to filter down into the schools. We are going to make do with people who have

qualified in engineering, who are teaching physics as a "stop gap." The interest in the subject will be minimal; for them it is just a job, and they have no interest in the subject. If they start from that point at the university to make the subject more applicable to the students, I think it might filter down to the schools. We will then get people in the department who have interest in the subject, who will teach in the schools, and thereby pass the interest on to the students. But right now nothing is being done to improve on the situation and the schools can't do much.

JK: I also observed that students did not have practical manuals and some even do not have a textbook. Does this cause problems in teaching the subject?

A: The students are given the "O" level syllabus in form IV, so a lot of them have their textbook for the "O" level in form III, where they actually start the subject. Students study general science in forms I and II. There is a text book prescribed; most times teachers give notes. With the notes and working in the library, students should be able to get as much information as necessary for the course. I haven't experienced that as a problem.

JK: Could you think of suggestions for improving on the methods of engineering graduates who teach physics?

A: I think that workshops and seminars could be organized to update these teachers and other physics teachers on recent methods of teaching physics. This will help because the problem lies in the

approach to teaching the subject. If these teachers are given some direction as to how to approach the subject to students starting physics for the first time, how to make it interesting and do demonstrations, perhaps it might go a long way to help. We have a well-stocked lab in this school, at least up to the sixth form level, with the exception of a few items that are short. I found out that other teachers in the lower forms do not make use of the lab. I am not saying that students in the lower forms should do practicals, but I think that even if once a month teachers take them to the lab and do a class demonstration on what has been taught, show the students the instruments that are available, let them see what some of these things look like, that might help the students not feel that the subject is abstract. Some of the relation to practical can be pointed out in everyday life. From such workshops and seminars, some upgrading of the teachers' knowledge coupled with methodology in the subject will be necessary. A programme could be developed where the teachers themselves will appreciate that physics is a practical subject so that they might be able to pass it on to the children.

JK: Will the present economic situation in the country encourage teachers to prepare adequately to teach?

A: Of course, no. There is going to be a problem in schools, with education in general. Yes, more in subjects where people have the conception that it is difficult. Nobody is going to make an effort, spend time and spend energy with a subject that they probably think is difficult, and yet they are not paid for it. There is no adequate reward for the

amount of effort that it takes to make the subject interesting. Especially if it is someone who is not interested in the subject, it will be difficult. Take somebody from the engineering field. He imagines that in his field if he has a job he will earn about 10 times what he is presently earning as a teacher. He is going to do about one-fifth of the amount of work he feels the salary deserves. It is going to be difficult.

The interview with Teacher A concludes the data reported from School A. We turn now to a similar account of practical work at School B.

Physics Teaching at School B

The facilities in school B have deteriorated considerably. Very little basic equipment (rectangular glass blocks, triangular glass prisms, etc.) is available. Students worked in groups of five in practical classes; there were seven rectangular glass blocks for a class of 46 students, and two students each brought a glass block to make a total of nine. Two sets of practicals were scheduled for a period of two weeks; the students performed one while teacher B did a demonstration of the other. The students could not do the second practical because there was only one triangular glass prism available. Teacher B conducted demonstrations of the scheduled practicals during physics classes one day prior to the practicals. These demonstrations and revision classes were teacher-directed; he did the talking, explaining and writing of theory for practicals on the blackboard. During these demonstrations teacher B gave step-by-step explanations of how to conduct practicals. He also told students how to record and analyse their results. During practical classes teacher B wrote the instructions and drew diagrams and tables for

the tabulation of results on the blackboard. Teacher B described observations students should make, gave direct answers to students' questions about the experiment, and performed parts of the experiment for students in response to questions about procedure. Teacher B went round directing and assisting students with their work as and when the need arose.

Two sets of revision lessons and demonstrations were observed and recorded. The first lesson and demonstration was on measurement of the refractive index of glass; the second involved measurement of minimum deviation in a triangular glass prism. Below is an excerpt from the lesson and demonstration on the refractive index of glass.

Lesson and Demonstration before a Practical Class

B: We are going to look at the laws of refraction of light and how to measure the refractive index of light for a given medium. [The teacher draws a standard diagram for light passing through a glass block, bending toward the normal on entering and away from the normal on leaving.]

Let mm' represent the boundary between the media—air and glass.

NO represents the normal to the plane.

AO - the incident ray

OB - the refracted ray

i - the angle of incidence

r - the angle of refraction

The angle between the normal and the incident ray is called the angle of incidence. The angle between the normal and the refracted ray is called the angle of refraction. The laws are

1. The incident ray, the refracted ray and the normal all lie on the same plane.
2. The ratio of the sin i to sin r is a constant.

This constant is called the refractive index from one medium to another; it is usually designated by n. Now let us look at refraction from another point of view. Who can define refraction in terms of the velocity of light from one medium with respect to another medium?

S: (Inaudible).

B: Anybody else? Yes.

S: The velocity of light from less dense medium is greater than the velocity of light in the other medium.

B: Given two media, the ratio of the speed of light in medium one to the speed of light in medium two is a constant. It can also be defined as

$$\frac{\text{THE VELOCITY OF LIGHT IN MEDIUM ONE}}{\text{THE VELOCITY OF LIGHT IN MEDIUM TWO}} = \text{CONSTANT.}$$

At the end of this class you should know how to find the refractive index of a glass block. I will also explain to you how to find the refractive index using the idea of real and apparent depth.

What happens when an object is immersed in water ?

S: It increases in size.

B: Is that true ?

S: No.

B: What actually happens ?

S: It appears to be nearer.

B: It appears to be raised. So therefore you have an apparent depth and a real depth. What is an apparent depth ?

S: (Inaudible).

B: The apparent depth of an object is the depth of the object as it appears raised. [Teacher B sketches on the blackboard to explain the difference between real and apparent depth.] What is the real depth ?

S: The actual depth of the object.

B: We all know how to read the meniscus of liquids. What is the shape of the meniscus of water ?

S: Concave.

B: The real depth is the distance from the object to the lower part of the meniscus. The apparent depth is distance of the image of the object as it appears raised inside the liquid (in this case, inside the beaker). So we can also define refractive index as the ratio of the [real] depth to the apparent depth. Having arrived at these definitions of refractive index, the most important point I want you to note is how to find the refractive index of glass. What we have to do in the lab is how to find the refractive index of glass. In this case what will be the first medium?

S: Air.

B: What will be the second medium?

S: Glass.

B: I will demonstrate it to you. In any experiment you do, it is important that you read the instructions first. A lot of students fail the G.C.E. "O" level practical examination because they do not know what to do. They are not patient enough to read the instructions well. You put a piece of drawing paper on the drawing board. The first step is to draw the outline of the rectangular glass block. The whole idea is for us to be able to define an incident ray and then find the angle of incidence, from which we find the angle of refraction.

Stick two pins on the incident ray. Light rays reflected on the pins will pass through the glass block. Then we search for the images of the two pins on the other side of the glass block. Come and watch the images on the other side of the glass block. Do you see the images of the pins? Then the next thing you do is to find by using two other pins the images of the first two pins so that they coincide. You will first of all see an image; then you will use it to locate the second image. After that, remove the glass block and join the points of the two searching pins so that they touch the lower side of the glass block outline.

Draw the normal through the glass block outline because the angles of incidence and refraction are measured from it. Join the two refracted points. The angles are now well defined.

This procedure is repeated for other angles of incidence and you will get resulting angles of refraction. You will have to do this in the lab; this is just a demonstration. As we go along in the lab I will explain to you better.

Now let me show you how we tabulate the results. For each angle of incidence, you will have an angle of refraction; then you will have sine of the angle of incidence and sine of the angle of refraction.

i	r	sin i	sin r	sin i/sin r

You can then plot the values of sin i against sin r. If you are accurate enough you will get a straight line graph passing through the origin. If the graph is a straight line passing through the origin, what type of relation is that? [Teacher draws a straight line graph on the blackboard.]

S: Direct relation.

B: Some students because of examination fright construct two separate tables. [Teacher illustrates by drawing two sample tables on the blackboard.] This is wrong. The table should be a composite one having all the values together. In all the experiments you do, make sure that you enter your readings in a composite table. The other important thing is in taking your readings, if for instance the angle of incidence is 32 degrees, it should be written as 32.0 degrees. Examiners penalize if you record your readings without the appropriate decimal points. The graph is a straight line because it is a direct variation, and so for all the values you take, the ratio of sin i to sin r will give you a constant value. The vales for the quotient of the ratio of sin i to sin r may vary, but you will have to find the mean value of all the values. The next important thing is how to find the refractive index from graph. To find the refractive index you only need to find the slope of the graph. What is a slope?

S: The gradient.

B: The gradient in that graph will be the rise in the sin r axis divided by the corresponding increase in distance along the sin i axis. This will be the experiment you will be doing during our next practical.

As the preceding dialogue suggests, the practical involved measurement of the refractive index of a glass block. (Four of the school's seven rectangular glass blocks were chipped on the edges.) Students were organised into nine groups, eight groups with five students in each and one group with six students. A leader for each group was appointed; his duties were to control the use of the available materials for the practicals, copy instructions as the teacher dictates in front of the class, see that every student in the group participates in the practical, and copy the results of the practical on the blackboard for analysis. Other members in each group copied the ray diagrams from the blackboard into their exercise books. Every member of the group took part in setting up the practical; some put more effort in the work than others. Some students moved from one group to another, watching how they did their work and going back to show other members in their group what to do. About 20 minutes before the end of the practical class, each group leader copied their results on the blackboard. Then Teacher B calculated the refractive index and compared the results for each group. Students were expected to go over the calculations in the analysis on their own. Students do not prepare written reports of the practicals.

At the end of the practical class Teacher B identified two students whom the researcher interviewed separately to explore the extent to which they understood what they were doing and to get their views about the practicals they do at school. The students were group leaders; one of the interviews is reported below.

Interview with a Student after a Practical Class

JK: What was the practical about?

S: The practical was about refractive index of a rectangular glass block.

JK: What were you required to investigate in this practical ?

S: We were required to calculate the angle of incidence and the angle of refraction.

JK: Did you get some readings ?

S: Yes, we got values like 28 degrees as the angle of incidence and 18 degrees as the angle of refraction. But they were not that accurate.

JK: How do you know that those values are not accurate?

S: The size of the group does not permit one to take accurate readings because every other person in the group is pushing the other in order to watch for the image. These movements and pushing around the instrument does not permit the group to get accurate readings.

JK: Suppose you were working alone with the instruments, which area would you have problems with?

S: My problem will be in finding the angle of refraction. Because if you stick pin one and two, you have to move to the other side to trace the image of the two pins before you stick the other two pins. It is difficult to determine the exact position of the images of the first two pins because they seem to be in a straight line with the searching pins from any point on the lower surface of the glass block. My problem was determining the exact position of the emergent ray in order to determine the angle of refraction.

JK: How are you going to analyse the values you have recorded?

S: The values can only be analysed if tables of values are provided. The values should be entered in the tables and then calculated.

JK: Based on the practical that you have just done, how are you going to analyse your values in order to provide an answer to your investigation?

S: It depends on the accuracy of the values.

JK: Suppose the values are accurate, how would you use them to provide an answer to your investigation?

S: Then the value of the refractive index of air to glass will be given, then you will use the relationship of sin i divided by sin r.

JK: Can you think of another way of analyzing your data?

S: That is the only way so far that I have been instructed in.

JK: Didn't your teacher talk about using a graph to analyse your data?

S: Oh yes, you can use a graph. You will also be asked to draw a straight line graph.

JK: How will you get the refractive index of the glass block from the graph?

S: I will have to go and look it up in my text.

JK: Will you have problems in plotting your values on the graph?

S: No.

JK: Do you have any problems that you could discuss with me?

S: We have got many difficulties. In the first place the number of glass blocks were not enough for the number of students in class. Secondly,

we have been organized in groups of five and I had difficulty in understanding how to carry out the practical. Even some members of my group did not understand the aspects involved in the practical. Some members in the group did not take the work seriously because they attend private lessons after school; they cause noise in class to distract our attention.

JK: How did you get your values when you did not understand how to carry out the practical?

S: A friend from another group came over to assist us. He is attending a private lesson.

After observing two lessons and demonstrations, observing students do a practical in groups of five in the laboratory, and conducting two interviews each with two students, an interview was also conducted with Teacher B. The purpose was to elicit the teacher's views on physics practicals and on the teaching of physics as a subject, to cross check issues raised by the two students and to better understand the observations made in the classroom and the laboratory. In this interview, Teacher B suggests that practical work contributes to understanding concepts and to seeing the "practical" side of physics as a subject. Yet the discussion of students' difficulty in following instructions suggests an alternative view, one that assumes that understanding follows from reading and being told.

Interview with Teacher B

JK: How are students selected to study physics?

B: In this school students are selected on the basis of their performance

in physics in the previous form. For instance when students get to form IV, senior teachers in the physics department look at records to see how well a student has been doing in physics. Of course not only in physics but in mathematics and other science subjects so that they could be streamed. In the area of physics, we look at the student's grade in the previous form.

JK: Why do students do physics practical?

B: In my mind I think they do these practicals so that they could better understand the concepts in physics. The practicals tie up students' theoretical knowledge with the understanding they get from playing with the materials in the lab. Without this I don't think there will be any holistic understanding of the subject.

JK: How often do students do practicals?

B: On the average in this class which I teach, they do practicals once a week, but since we have a double period it covers both practical and theory that time. But we are handicapped by the unavailability of materials. I would like to see the boys do practicals about three times a week at least because the practicals are so important that it makes the students understand the theoretical part better. I only conduct practicals once a week. Actually it should have been more than that but due to the unavailability of materials we cannot do otherwise.

JK: In one of the practicals students worked in groups of five and in the other practical you did a demonstration while students crowded around you. Would you like to explain the difference in methods?

B: Yes, exactly, that points to the fact that we do not have basic materials like rectangular glass blocks and triangular glass prisms. The demonstration was intended to give students an insight of what the practical involved so that when they go to other schools for extra work or find materials later on to do the practical themselves they will be able to do the practical better. It is very difficult for me right now to conduct a practical the way it should be conducted.

JK: Why do students go to other schools to do practicals?

B: Well, there may be personal reasons from the students, but I think that they go to other schools because they have more materials than our school. In these schools students do private work and they get the actual feel with the materials.

JK: Do you by chance know whether students pay for the private work in these schools?

B: I am pretty sure that they do pay because I could not imagine a teacher giving extra work to students as charity.

JK: With the few practicals your students have been doing, which aspects do they have difficulty with?

B: The difficulties they face sometime arise from their misunderstanding of the instructions. I believe some of them do not understand the instructions, they just jump on doing the practicals and so they have to go back and forth reading the instructions, whereas if they have understood the instructions earlier they should be able to do the practicals. And also you cannot remove the fact that some of them do

not yet know the equipment we have in the lab, how it works and how it should be set up, etc. They know the basic equipment but I wonder if they know how to use the micrometer screw gauge and the vernier caliper for instance. They have studied how they operate and their uses in the lower forms but since we do not have any in the lab presently I doubt if they know how to use them. The students know about them theoretically but they may not have seen them. That is one of my fears about students studying physics up to form V in this school. Students should know about these basic instruments, how they work and how to use them.

JK: Could you explain what you mean by "they just jump on doing the practicals"?

B: Most times in the lab we use the same or similar materials and instruments to explain different concepts. So when students see the same materials and instruments they may think that they have been asked to do what they have been doing in class. Without reading the instructions properly they go on doing different things from what they have been asked to do.

JK: How often do students "just jump on doing the practicals"?

B: As often as they do practicals. I always tell them to read the instructions first before proceeding with any activity.

JK: How do you hope to get students to develop the practice of reading instructions before starting to work on practicals?

B: I hope to continue telling them to read the instructions before beginning any practical work.

JK: Besides the understanding of theory and getting grips on underlying concepts, do you conduct physics practicals with another intention?

B: Yes, I conduct physics practicals because I believe that by so doing the students will actually know that physics is not only a theoretical subject. In fact I feel that when I do practicals my main theme is to make sure that, whatever the case may be, the students should know that the subject is a practical one and it should be applied within our environment. However, we should be able to explain concepts practically.

JK: Do you also conduct physics practicals with the intention of preparing students for the G.C.E. "O" level physics practical examination?

B: Yes. In fact that is one of the main reasons, especially when students get to form V. Even in form IV the practicals are also geared towards the examination but they are more general in nature with the intention of getting to become familiar with the use of the equipment and materials.

JK: If there were no public examination, would you conduct physics practicals differently?

B: Well, yes, to some extent. There are certain practicals which students could do at home but since I am constrained by the public examination I conduct practicals that students will need for the examination. So if there was no physics practical examination I should

have diversified the practicals we do in form V and would spend some time on how to interpret experimental results meaningfully.

JK: Then what type of practicals do students perform in form V?

B: Practicals that are geared towards the G.C.E. "O" level physics practical examination.

JK: How do students relate the theory taught in class to the practicals they do?

B: After the practicals they are expected to interpret the results by way of drawing graphs and interpreting the graphs. For instance they might be able to find out that they learned in the theory class that the refractive index of glass is about 1.50, which is the theoretical value. If they perform an experiment in determining the refractive index of glass and they come up with a value close to that, then they know that they have proved what they learned in theory. Through practicals students can also find out that different glass materials have different refractive indices, which will prove the point that the speed of light varies in different materials.

JK: How would you describe the G.C.E. "O" level physics practical examination?

B: From the G.C.E. "O" level physics syllabus, one will see that the examination tests whether the students have been adequately prepared to study physics at the university or college. It still remains for us teachers to show the students that the knowledge of physics has to be

acquired not only for the examination or to go to university but could be useful to their environment.

JK: I observed that there were not enough instruments and materials for students to work with. How do you cope with this shortage, especially when you conduct the G.C.E. "O" level physics practical examination?

B: At the nick of time for the physics practical examination, I ask the principal to buy instruments and materials that are available locally. Others that cannot be bought locally can be got either from other schools or the university and college.

JK: How do you know which instruments and materials the principal should buy or get from other schools or university or college?

B: The examination council sends confidential instructions of materials and instruments required for the examination to the principal of the school. The principal in turn hands over the instructions to the teacher teaching physics in form V. The teacher then checks for the instruments and materials he has in his lab and those he does not have. It is from the confidential instructions that we know which materials and instruments to either buy or borrow.

JK: Is the shortage of instruments common to all the schools doing physics?

B: Yes. Some schools may have some materials and instruments. I am sure no school in the Western Area has everything in the laboratory. Some schools do not have any instrument in their laboratories.

JK: Does that mean that students in these schools do not do practicals in their regular classes?

B: Yes. In some of these schools teachers teach theory all the time because of the unavailability of instruments and materials.

JK: How then are students prepared for the G.C.E. "O" level physics practical examination?

B: In most of the schools practical classes are conducted only a few weeks before the examination. Students are drilled for the practical examination after teachers have seen the instructions required for the practical examination.

JK: Could you suggest reasons why some students that pass the G.C.E. "O" level physics examination do not perform well in practicals at college?

B: The process of acquiring knowledge in physics is not discrete but continuous. One has to start from the basic, then to the complex. If you have learned how to use an instrument, perhaps doing a practical might only involve a fraction of the knowledge you know about the instrument to get the result. So if you do not get the fundamentals earlier then you will eventually end up not being able to do much in practicals. If you have a crash program of practicals in schools so that the students can answer the practical questions, then they will not get the understanding of how to do practicals. This is why students face a lot of difficulties when they go to college. So if you learn to do an experiment so that you can answer a particular question in the exams, that does not necessarily

mean that you have actually acquired the necessary skills. The most important point is that students must acquire the fundamental skills and be able to use them later; otherwise students might end up passing the exams with good grades but unable to perform similar experiments at a later date.

JK: Do you think that diagrams assist students to follow instructions or do they create problems in practical physics?

B: They help a lot because in physics, as in biology, chemistry, and geography, diagrams play a very good role. Our students face a lot of difficulties trying to interpret things in English; if they have diagrams that represent concepts, then that will assist understanding. For instance, diagrams in electricity representing rheostat, key, ammeter, and voltmeter in practicals go a long way to help students follow instructions. If instructions are only written in English without diagrams, then students will be faced with greater problems. Diagrams go a long way to assist students to follow instructions and to conceptualize what they are required to investigate in practicals.

JK: If you were asked to prepare the G.C.E. "O" level physics practical examination, what type of questions will you set?

B: I will set short-answer questions and a practical, of course. But the practical will involve short procedures that will require students to write down their results for every step accomplished and finally the students will use the results to do an investigation. The present practical questions include all the necessary instructions but these instructions

should be in steps so that the student will know what he is required to do and measure. The instructions should involve short steps written in sequence so that students can easily follow.

JK: What are your views about physics teachers in general?

B: Physics teachers in Sierra Leone find it difficult to work in an environment where they do not have visual aids. Teachers face numerous problems, for example, the problem of getting equipment and materials and funds to buy materials that could be got locally. The majority of physics teachers want to leave teaching for other professions. Teaching physics is very interesting but if the conditions under which you are working are not favorable as compared to other jobs, then you end up not doing much. Physics teachers do not get job satisfaction because of the prevailing conditions in the schools of not having materials and equipment to work with and getting salary at the end of the month is not certain. Physics teachers should be more receptive to their students because we are losing a lot of them. The long term effect will be that there will be no students studying physics at the university and college. If physics teachers impart the necessary fundamentals to their students so that they become well grounded in physics in the secondary schools, then students will build on that foundation when they go to university or college. Physics teachers are very few, and teachers have to do part-time teaching in other schools so that these schools get the services of a physics teacher. A few engineers waiting for jobs are employed to teach physics in some

schools. These engineers face a lot of problems in the classroom because they were not trained to teach physics.

This interview with Teacher B completes the report of data from School B. The chapter concludes with presentation of data from School C.

Physics Teaching at School C

Physics classes were held on Friday afternoons (2:30-4:00 p.m.) and Saturday afternoons (12:00-2:00 p.m.). Students in forms IV and V attended those classes; students from other schools also attended these classes that were held after regular school hours. Facilities to conduct practicals in forms IV and V are not adequate in this school either. However, the few materials and equipment available in the laboratory are well cared for. Two sets of practicals were performed over a period of two weeks. One set of practicals was on optics (measurement of the refractive index of a rectangular glass block) and the other was on mechanics (the simple pendulum). Students attending school C performed the set of practicals in optics while students from other schools performed the set on mechanics.

In both lessons observed, the first 20 minutes were devoted to students from other schools working on practical work in mechanics. During this period Teacher C asked the rest of the class to read over the previous lesson while directing students in the mechanics group on how to proceed with the experiment. Almost every student in this set has a practical manual. The lesson of the day always started with teaching of theory followed by practical work in which the students work in groups of four. The lessons were teacher-directed, with Teacher C giving explanations and notes.

Practical work for the rest of the class was scheduled for the last 30 minutes of the teaching period. Students were placed in groups of four with a group leader for every group. Each group was given the same set of past G.C.E. "O" level physics practical question papers to work on. Teacher C stood in front of the class reading the instructions to the question and directing students how to proceed with the practical. Description of observations students should make, precautions students should employ in order to get reasonable values, the number of significant figures to use to record values and how to analyse the results were explained by Teacher C. Teacher C also went round each group assisting them with the practical work. Students did not analyse their results during practicals but were told to analyse the results at home.

The same practicals were performed the following week but with little or no direction from the teacher. Each group leader gave the group's results, which were compared with the results of other groups. The students did not submit written reports of practical work. Two students at School C were interviewed, as at the other two schools; these interviews were not transcribed when it was realized that they did not add to the comments made by students at Schools A and B.

An interview was conducted with Teacher C in order to get his views about physics practicals, the teaching of physics practicals and the problems in teaching physics in general. An excerpt from the interview follows. Teacher C reveals a different tone than Teachers A and B; he is respected for the results his students achieve on the examination. He speaks of practical work reinforcing theory, and works to have the two occur at the same time. He displays high regard for the examination system as it is presently organized, and this suggests a high degree of

coherence within his teaching and between his teaching strategies and the examination system.

Interview with Teacher C

JK: How are students selected to study physics?

C: Students are selected based on their performance in mathematics and physics in form III.

JK: Why do students do physics practicals?

C: The practicals are usually conducted to reinforce the theory which may have been taught. There are times when both the theory and practicals are conducted at the same time.

JK: I observed that you conduct practicals and teach theory at the same time. Why do you use such a strategy?

C: I found out that putting some of these concepts with a practical approach makes it very easy for the students to understand the concepts rather than doing them in an abstract manner. The practicals normally make it possible for them to be part of the learning situation because they are kept busy trying to observe what is going on and some of these concepts can be brought out without the students being told.

JK: How often do students do practicals?

C: Well nearly every week. There are times when topics may not have many practicals. These are the times practicals are not done.

JK: Do students have difficulty in performing practicals?

C: Well, based on my observations, those who turn out to be very cooperative, who may have worked very hard during the course of the year, tend to have easy work over the practicals.

JK: Do you also conduct practicals with the intention of preparing students for the G.C.E. "O" level physics practical examination?

C: These practicals have two aspects—to reinforce the theory and to get them prepared for the examination.

JK: If there were no public examination will you conduct physics practicals differently?

C: I would be forced to conduct practicals in order to reinforce the theory but I believe that, having the public examination in mind, then some of these practicals are given an approach that will be geared towards passing the examination.

JK: How do students relate theory to practice in physics, and what part do practicals play in this process?

C: Most of these practicals are not only geared towards reinforcing the theory which has been taught but there are times when these practicals will bring out observations which they have come across in their everyday life. So it has a two-fold aspect—to bring out the theory which may have been taught in that particular period and to help them explain certain behaviour or phenomena which they may have come across outside of the classroom.

JK: What type of practicals do students perform?

C: Practicals are done on all areas in the teaching syllabus.

JK: How would you describe the G.C.E. "O" level physics practical examination?

C: As for the standard, I will say it is up to standard and the papers are well drawn and they are geared towards getting the students to exhibit their basic knowledge of the concepts which they may have learnt.

JK: A teacher said that his students have difficulty in reading and following instructions. Do you also observe such difficulty in your students?

C: Well I have observed students facing such problems, especially those who have not been having enough exposures during the course of the year. But with my own pupils I must admit that only a few face this problem, probably because of their intelligence level or inability to understand basic English. But ruling off those factors, I strongly feel that if students have been given enough practice over the course of the year, then reading the practical questions in the examination should not pose a problem.

JK: Teachers allege that not all schools conduct physics practicals regularly except when the G.C.E. "O" level physics practical examination is near. What is your view on that?

C: Well I must admit that in fact we discussed that problem when we had the last science teachers' meeting. Most schools keep the practicals until the dying minutes for the examination.

JK: If you are asked to set the G.C.E. "O" level physics practical examination, what type of questions would you set?

C: I will draw questions based on the format which has been carried out by the Exams Council which I consider to be very impressive.

JK: A problem observed in other schools is the availability of apparatus. Do you have problem in getting apparatus to conduct practicals?

C: Well when I first came we used to have that problem but having discussed the problem with the principal it was decided that the number of students doing physics should be reduced, because the main problem was getting enough instruments for the number of students taking the examination. So by reducing the number we have been able to conduct the examination without going out to search for instruments.

JK: Don't you think that limiting the number will reduce the number of students who may want to study physics?

C: I don't want to feel so because we often cater for average and above average students. We always ensure that those with average ability and those above are catered for; the extremely weak ones are normally left out.

JK: Some students wear coloured clothes while others have on the schools' uniform. Why the difference in dress?

C: Those with coloured clothes are students from other schools that come for coaching in physics practicals.

JK: Is the principal aware of that?

C: Of course he is aware about that. I discussed it with him before ever they started to attend my classes.

JK: Why do you combine form IV and V physics classes and teach them as one class?

C: This is because I only have two days to meet with both classes. I have arranged it so that both classes will benefit from these meetings. Imagine that students in form V are continuing with the physics syllabus while students in form IV have just started the syllabus. So if those in form IV move on to form V they will be studying other aspects of the syllabus while students coming into form IV will be beginning the syllabus. It is a circular method for both forms. Students in form IV always begin the syllabus from a different point while students in form V end the syllabus from another point.

JK: How long do you hope to continue with this method?

C: I must hasten to add that this is a temporary method.

JK: You hold your classes after normal school hours. Why the time difference from the rest of the school?

C: I discussed my new schedule with the principal and he agreed to it. I could have resigned my job as a physics teacher but there would have been nobody to replace me. In order to help the children I conduct my classes the times I do after attending lectures in the day.

JK: Don't you think that the children will be tired and feel bored after being in school since 8:00 a.m.?

C: I do think about them but there is nothing I can do. This is why I teach theory and practicals as the lessons progress so that the children will not feel bored and tired.

JK: What are your views about physics teachers in general?

C: It is a very sensitive issue. . . . There is a need for the university to produce more graduates in that particular area. Physics teachers have been quite few in number and this has affected the teaching of the subject in most schools. The majority of physics teachers want to leave because there are no incentives to keep them in the profession and I don't think that the reward they get as salary is comparable to the effort put in studying the subject.

This presentation of data concludes with a brief summary of features of practical work in physics at the three schools. In school A students worked individually on a rotational basis on every set of practicals. Teacher A gave notes on procedures about practicals and required the students to write a formal report on every practical but she did not discuss the results of the practicals with the students. In school B students assist with the provision of equipment for practicals and they work in groups of five. Teacher B gives revision lessons of the theory for the practical to be performed, followed by demonstration lessons. Teacher B analyses students' practical results; students do not write formal reports on practicals they perform. In school C classes are held after regular school hours. Physics classes for forms IV and V are scheduled for the same time and students from other schools also attend these classes. Practicals are conducted after the theory has been taught. Practicals from past question papers are performed by the students, first with much assistance and direction from Teacher C and later without much help from the teacher. Students work in groups and they do not write formal reports on the practicals they perform. Chapter 5 presents an analysis of the data.

CHAPTER 5

ANALYSIS AND INTERPRETATION OF THE DATA

This chapter analyses and interprets the data presented in Chapter 4. An account of what teachers say they would like to do in practical work is followed by descriptions of what they say actually happens in the laboratories. Then attention turns to the pressures and constraints that help to explain why teachers conduct practicals as they do and to the consequences that follow for their students.

Teachers' Goals for Practical Work

The teachers stated that practical work should improve students' understanding of concepts in physics and also provide an opportunity for students to work with materials and equipment, increasing their involvement in the learning situation. The three teachers stated their views on why students do physics practicals in the following ways.

> A: Well to aid the theory, to give a better understanding of the theoretical aspect of the subject.
>
> B: In my mind I think they do these practicals so that they could better understand the concepts in physics. The practicals tie up students' theoretical knowledge with the understanding they get from playing with the materials in the lab. Without this I don't think there will be any holistic understanding of the subject.
>
> B: Yes, I conduct physics practicals because I believe that by so doing the students will actually know that physics is not only a theoretical

subject. In fact I feel that when I do practicals my main theme is to make sure that whatever the case may be, the students should know that the subject is a practical one and it should be applied within our environment. However, we should be able to explain concepts practically.

C: Practicals are usually conducted to reinforce the theory which may have been taught. There are times when both the theory and the practicals are conducted at the same time.

C: I found out that putting some of these concepts with a practical approach makes it very easy for the students to understand the concept rather than doing it in an abstract manner. Practicals normally make it possible for the students to be part of the learning situation, because they are kept busy trying to observe what is going on and some of these concepts can be brought out without even the students being told.

The teachers' goals and aspirations for practical work show interesting similarities to the arguments developed by science education researchers who have turned their attention to the role of the laboratory in the teaching of science. The teachers' responses suggests that the laboratory should provide the initial direct experiences that will bring out students' existing conceptions and permit the development of new concepts in subsequent teaching; this is similar to the arguments of Renner, Abrahim, and Birnie (1985). Through practical work students will be exposed to the experiences that are to be acquired and which should form the basis for expanding the observed phenomena into new understandings of concepts (Renner, 1982). Driver (1983) argued that after performing practicals, students

should be involved in discussion in order to develop the process of making sense of their practical experiences.

Renner's (1982) "Learning Theory B" described earlier is a teaching approach that is based on concept-building. This approach aims at mastery learning of content and guiding students to relate and expand their understandings of concepts. There are three major stages to this approach. The first stage involves exposing students to the phenomenon illustrating the concept using materials and instruments related to the subject. It is at this stage that teachers perform demonstrations illustrating the phenomenon without telling the students what the immediate result would be. The students' role at this stage is observing the phenomenon. The second stage involves allowing students to describe their observations, and students may use their intuitive ideas to describe the observations (Brook et al. 1984). Their intuitive description may be correct but lack the use of scientific terms and vocabularies that will succinctly describe the observed phenomenon. It is at this stage that teachers could intervene, introducing the generally accepted scientific vocabularies or terms and symbols describing the observed phenomenon underlying the concept. The final stage to this teaching approach involves providing experiences for the students to expand the meaning of the concept. This is the stage where practical work for the students comes in. Practical work becomes the process through which students should expand and build on their understanding of the concept. Students could further expand their understandings through reading from their textbook. Their problems in understanding the explanations given in their textbook should be reduced because they will be familiar with the scientific terms, and can visualize what is being explained because they have seen a demonstration

of it. This approach may fit Shymansky and Penick's (1979) description of the importance of laboratory practical work.

> The primary goal of the laboratory experience for the beginning science student should be to reinforce through concrete examples and direct manipulation of materials the same basic concepts presented as an abstraction in the lecture or text. Unless this happens or is facilitated, the lab may be a waste of time. (p. 195)

However, the following extracts from observations of teachers conducting practical work show that their instructional methods tend not to achieve their goals of concept-building through practical work.

How Teachers Conduct Practical Work

Though the teachers believe that practicals assist students to understand the theory, there are factors that constrain them from teaching practicals as they would like to. Perhaps the major constraint that influences their teaching method is the G.C.E. "O" physics practical examination. The teachers say that the practicals students do in forms IV and V are to prepare them for the physics practical examination. The teachers expressed this purpose of the practical work in the following ways:

> A: Yes. In fact that [preparation for the examination] is one of the main reasons especially when students get to form V. Even in form IV the practicals are also geared towards the examination but they are more general in nature with the intention of getting to become familiar with the use of the equipment and materials.

C: Practicals have two-fold aspects, to reinforce the theory and to get the students prepared for the exams.

The practicals students perform do not assist in illustrating and explaining concepts. The teachers teach specific skills on how to carry out formal investigations for the purpose of an examination. This involves teaching students to become acquainted with concepts and manipulate equipment so that the knowledge and skill derived from such practicals could be used only to pass the physics practical examination. The teachers described the type of practicals students do in these terms:

A: Right now I know there are a lot of schools where no practicals are conducted before the exams. Towards the exams they [teachers] get the students to do one or two practicals that they feel might come in the exams and that is it.

B: Practicals are geared towards the G.C.E. "O" level physics practical examination.

B: In most of these schools practical classes are conducted only a few weeks before the examination. Students are drilled for the practical examination after teachers have seen the instruments required for the practical examination.

C: Well, I must admit that in fact we discussed that [schools do not conduct physics practicals regularly] when we had the last Sierra Leone Association of Science Teachers meeting, that most of the practicals [in the schools] are kept until the dying minutes for the examination.

Teachers employed methods of instruction that facilitated achieving their major objective of preparing students for public examination. Teacher A provided her students with the opportunity to work independently with the instruments while conducting practicals. She only assisted students with their work when they asked her to do so. She reports that she does not discuss their work regularly because students neglect their work and the class is large, with about 20 students to teach and supervise. She believes that giving notes and extensive explanations promotes students' understanding of physics practicals and physics in general. She also believes that students should work independently, using their textbooks and finding resource materials from the library.

This method of instruction is what Renner (1982) refers to as "Learning Theory A," in which the teacher informs the students and then the students later verify what they have received from the teacher by performing experiments with known outcomes. The method of teaching theory and then later performing standard sets of practicals that require the verification of established results could be described as the "traditional" approach. In this approach students perform a standard sets of practicals from laboratory manuals. These manuals describe experiments and methods to either "determine" or "verify" standard physical constants. The students performed standard sets of practicals but without laboratory manuals. They used their textbooks to follow instructions for performing the limited number of practicals made available to them.

Renner's (1982) "Learning Theory A" is a teaching approach that aims at informing and giving students facts and basic principles which should be verified by using standard sets of laboratory experiments. The purpose of this approach is

specific: mastery of content. This approach is based on the belief that the teacher is the reservoir of knowledge, and the knowledge students possess depends upon what the teacher tells them. This belief is commom with institutions where the curriculum is examination-oriented, and the approach has three stages. The first stage is to inform the students what they should learn. In this stage the teacher lectures and dictates notes, describes standard practicals to verify the facts and basic principles students have been told about, and refers students to their textbooks. The role of students at this stage is to listen carefully and take dowm notes. In the second stage, students perform standard set of experiments to verify the facts and principles they have copied. It is at this stage that students are required to attach meaning to the underlying basic principles of the concepts that they have been given during the lecture stage. Unfortunately, most students have difficulty in relating the theory they have heard to the practical work they should do. The third stage in this teaching appraoch involves practicing to answer questions and solving problems from textbooks. The three teachers in this study used methods similar to Renner's (1982) "Learning Theory A" approach.

The method used by teachers in Schools B and C involved demonstration of the practical work students should do one day prior to the practical class. During these demonstrations the teachers told students everything they needed to know, including the expected results. This method of instruction, according to Raghubir (1979), deprives the students of the opportunity to learn for themselves. The students worked in groups (five in a group) when performing practicals, but group work does not provide an opportunity to observe students individually at work and it does not provide students with the opportunity to independently manipulate instruments.

Rather, group work encourages some members of the group to rely on others for the completion of a practical, thereby failing to acquire the appropriate skills. In addition, there were times when the teachers had to perform demonstrations in place of practical work because of the unavailability of equipment. The students believe that group work and demonstrations do not permit them to participate fully in their learning experiences. One student commented about the limitation group work places on him:

> S: Well, eh . . . yes, there would have been more concentration, participation and speed in performing the practical. Working with four other students reduced the rate at which I worked.

Pressures and Constraints on Practical Work

As mentioned earlier, one of the constraints that forces teachers to teach practicals in the ways described is the formal practical examination taken by students at the end of form V. In actual practice, the three teachers placed more emphasis on conducting practicals in order to prepare students for examination than on providing a means for understanding physics concepts. Teachers generally commence teaching the G.C.E. "O" level physics syllabus in form IV but do not conduct practicals until form V; in form IV, they only teach theory. This arrangement is said to permit more time for complete coverage of the syllabus. There may be an interval of six months between the time teachers present theory to the time students do practical work. This challenges the students to remember and link what they had first tried to understand in form IV to the practical work they are required to do in form V. Inevitably, the type of practicals teachers conduct in form V are those

that are most relevant to the examination. Teachers are limited to conducting only a few experiments in order to cover material required by the theory examination in the restricted time available to them. Below are some of the reasons teachers gave for giving less emphasis to practicals.

> A: But we are only starting the "O" level syllabus effectively in form IV. That means that we have about a year and a few months and that is not enough. We have to select those experiments we feel will likely come in the exams. concentrate on those. and just do one or two that are supposed to assist the theory the students learn.
>
> C: I will be forced to conduct practicals in order to reinforce the theory but I believe that having the public exams in mind, then some of these practicals are given approaches that will be geared towards passing the exams.

The other factor that constrained teachers from teaching practicals the way they would like is the shortage of equipment and materials to conduct practicals. Although the schools' laboratories are fairly well built, they lack basic instruments and materials to conduct practicals in forms IV and V (Sawyerr, 1969). The practical work students performed in form V was limited to those experiments for which equipment and materials could be found in the schools. In School B students had to go with rectangular glass blocks in order to have sufficient equipment to perform practicals. Students from other schools attended practical classes in School C because they did not have equipment and materials to do practical work in their schools. Lack of equipment and materials coupled with the number of students in each class in Schools B and C forced students to work in groups of five. Lack of

equipment caused Teacher B to conduct a demonstration in place of a scheduled practical. The teachers normally borrow instruments from the university and M M T C in order to conduct the formal practical examination, and the situation became very serious after November 1989. Some physics teachers from other parts of the country went to Freetown to borrow equipment from schools and colleges in order to prepare students for the June 1990 G.C.E "O" level physics practical examination (A. R. Jones, personal communication, May 28, 1990).

Consequences for Students

The teachers' concerns to complete the physics syllabus for the examination coupled with the limited availability of equipment and materials inhibit their effort to teach physics practicals the way they would like to. Students' expectations for the examination were high; their future educational careers depend on their success in the G.C.E. "O" level examination. In some instances, they were not satisfied with the approach adopted by their teachers; this led them to attend private lessons. They suggested that the methods employed by their teachers did not enable them to understand what they were doing in the practicals. They also felt that practical work should have started in form IV in order to acquire adequate practice with instruments and better understanding of how to do practicals. Their concerns were to do practicals that would give them practice in the skills of manipulating equipment and materials, and analysing data for the purpose of passing the examination.

The students experienced some difficulties in performing the few experiments observed. The students could explain what they were to investigate but they did not seem to understand what it involved. Explanations of their observations were based

on common sense rather than scientific reasoning (Brook, Briggs, Bell, & Driver, 1984). The students did not display understanding of basic scientific facts required for the work they were attempting. They could state the principles underlying the practicals but could not apply them to the investigations. They could manipulate instruments in order to vary measurements but could not explain the reasons for such variations, nor could they analyse their data. True to Driver's (1983) observation, the students do not discuss their experiences with the teachers after practical work. This appeared to contribute to the students' difficulties in making sense of the data, seeing the relationship between variables in performing practical work, and explaining their experimental results in relation to the underlying concepts. Selected excerpts from the data are given below to illustrate some of the inadequacies students demonstrated.

Students did not display understanding of basic scientific facts required for the experimental work. From the perspective of "theory first, then practice," students would be expected to learn certain concepts before attempting laboratory work. From the perspective of experimental activities as part of concept-building, one would not expect prior understanding. We can see in the following example how this is so.

Example (School A): Determining acceleration due to gravity

JK: I observed that you were varying an aspect of the pendulum when you were performing the practical. Which aspect were you varying?

S: The oscillation.

JK: What causes oscillation to vary?

S: The to and fro movement.

JK: What makes the to and fro movement to vary?

S: [No response]

Students could state the principles underlying the practicals but could not apply them to complete the analysis of their data. The following example illustrates this point.

Example (School A): Determining the specific heat capacity of a metal

JK: How do you hope to analyse your readings?

S: After you have got the mass of the solid, mass of the calorimeter, mass of calorimeter and water, the initial temperature of the water in the calorimeter and the temperature of mixture in the calorimeter, you subtract T1 from T2 so that you will get the temperature of the calorimeter.

JK: What were you investigating during the practical?

S: (No response)

This situation highlights the tension between theory-verification and concept-building as alternative purposes for laboratory work. When theory precedes experience, it is not surprising that difficulties arise in attaching that theory to practical situations. When experience precedes theory, the theory is developed in direct response to the experiences (Renner, 1982).

Students could follow instructions and manipulate instruments in order to vary measurements but they could not explain the reasons for such variations. In this particular experiment, there is considerable "conceptual distance" between the data that generally produce good results from a formula and the analysis of forces that explains the formula itself. When theory is presented first, without experience, it is

not surprising that students experience difficulties in explaining why they do particular manipulations. The following example illustrates this point.

Example (School A): Determining acceleration due to gravity

JK: Why do you have to measure time?

S: I measured time to find . . .

JK: Did you count the number of oscillations for each length?

S: No.

JK: Why do you have to measure oscillation and time?

S: In order to draw the graph.

The same student could not distinguish between the frequency and period of a pendulum swing, and this difficulty is again understandable when the distinction has been "learned" in theory rather than in practice.

Example (School A): Determining acceleration due to gravity

JK: What variables will you use to draw the graph?

S: The mean time, which is the periodic time and the number of oscillations.

When theory precedes experience, it is natural that students' efforts to analyse data will focus on obtaining a correct value that has already been "given" to them. This takes attention away from the process by which a strategy for interpreting data is found, applied, and judged to be adequate. The following example illustrates this point.

Example (School B): Determining the refractive index of a glass block

JK: How are you going to analyse the values you have recorded?

S: The values can only be analysed if tables of values are provided. The values should be entered in the tables and then calculated.

JK: Can you think of another way of analyzing your data?

S: That is the only way so far that I have been instructed in.

JK: Didn't your teacher talked about using a graph to analyse your data?

S: Oh yes, you can use a graph. You will also be asked to draw a straight line graph.

JK: How will you get the refractive index of the glass block from the graph?

S: I will have to go and look it up in my textbook.

Some of the students copied results from their friends. Very few students could associate calculation of the slope of a line as one of the ways experimental data can be analysed and that the slope gives an average value for the data collected.

In addition to the inadequacies observed, the students also admitted having difficulties in performing practicals. For example, the students had difficulty with locating the image of an object using search pins. According to Colton (1982), this was because students confuse ray diagram representation with the actual real representation of the object pins and the searching pins. Other types of difficulties students encountered were due to lack of appropriate content knowledge, lack of practice using equipment, and limited illustrations of scientific facts that they have been taught in schools. The following examples are illustrative.

Students confused ray diagram representation with actual real representation of the object pins and the searching pins. Here again, the explanation presented before experience interferes with the attempt to make sense of experience.

Example (School B): Determining the refractive index of a glass block

S: My problem will be in finding the angle of refraction. Because if you stick pin one and two, you have to move to the other side to trace the image of the two pins before you stick the other two pins. It is difficult to determine the exact position of the images of the first two pins because they seem to be in a straight line with the searching pins from any point on the lower surface of the glass block. My problem was determining the exact position of the emergent ray in order to determine the angle of refraction.

Students lack content knowledge, practice, and illustrations of scientific facts. When practice is verification of theory, students acquire vocabulary that the teacher assumes signifies understanding. Yet it is possible for very fundamental misunderstandings to persist until challenged by the practical context.

Example (School A): Determining the specific heat capacity of a metal

JK: Which aspects of the practical did you have problems with?

S: I did not know how to measure the temperature at first.

JK: What do you mean by "I did not know how to measure the temperature"?

S: That was my first time I measured the temperature of a liquid, so I did not know how to go about it.

Example (School A): Determining acceleration due to gravity

JK: What were your problems?

S: I did not know that I should find the time for one oscillation. I only measured T1 and T2.

S: I also had problem in counting the number of oscillations.

JK: Could you explain yourself further?

S: When you are swinging the pendulum you don't have to just swing it in a large scale, you just have to touch it a little bit in order to get an accurate result. So at times the pendulum will stop swinging when I still have not yet counted the number of oscillations. To be fair with you I did not understand anything in the practical.

Example (School B): Determining the refractive index of a glass block

S: My problems were how to get the refractive ray and the angle of refraction. I thought that the emergent ray was the refracted ray and the angle which it makes with the normal on the other side of the glass block was the angle of refraction.

These examples illustrate some of the difficulties experienced by students in their practical work in physics. What many teachers regard as basic and fundamental procedures are not easy for students to learn when time, equipment, and individual access to equipment are restricted.

However, these difficulties were not necessarily due to the students' lack of ability. Students put in the science streams in form IV in each of the schools are those with above average achievement in the sciences and mathematics in the lower forms. It is assumed that these students have acquired the fundamental principles that will enable them to comprehend basic scientific facts and mathematical relations if they are properly explained and demonstrated. Even the teachers know that the students' background in science are strong enough to permit them to develop the concepts and skills required for the G.C.E. "O" level physics practical examination.

Selection of students to study physics in form IV and subsequently in form V in the three schools were based on criteria that were outlined by the teachers.

A: Well usually after their third form they are streamed, invariably according to their performance in the different subjects. Those who are mathematically good and seem to have the aptitude for the sciences go into the science stream where it is automatic they have to do physics. The others are streamed into the arts, economics and commercial. So it is automatic they do physics in form IV if they have been streamed into the science stream.

B: In this school students are selected on the basis of their performance in physics in the previous form. For instance when students get to form IV, senior teachers in the physics department look at records to see how well a student has been doing in physics. Of course not only in physics but in mathematics and other science subjects so that they could be streamed. In the area of physics, we look at the students' grade in the previous form.

C: Students are selected to do physics based on their performances in mathematics and physics in form III.

Summary

This analysis and interpretation has described what the teachers would like practicals to be, presented a description of an adaptive application of Renner's (1982) "Learning Theory B" to physics practical instruction as an example of that concept-building approach, and described how teachers actually do conduct

physics practicals in their laboratories. The instructional methods the three participating teachers employed to conduct physics practicals have been interpreted in terms of Renner's (1982) "Learning Theory A," which describes theory-verification approach. The data were further analysed and interpreted in terms of the constraints that make teachers teach practicals as they do and the consequences that the students face because of the methods used to teach physics practicals. Generally, teachers have good intentions of conducting practicals as they teach theory in order to illustrate concepts and provide activities that promote student understanding. Because of the public examination and the amount of work that is required to cover the curriculum for that examination, teachers tend to put less emphasis on practicals. Teachers also made the point that shortages of equipment and materials, textbooks, and laboratory manuals make the teaching of physics in general a difficult task. As observed and reported, teachers drill their students in skills specific to the practical examination and guide them on topics expected to appear in the practical examination in order to compensate for general inadequacies in students' scientific skills and techniques. The practice of drilling students specifically for the practical examination helps to explain how students pass the G.C.E. "O" level physics practical examination but later demonstrate a broad range of inadequacies in the physics laboratory. The long-range consequences for students certainly seem undesirable, for they have passed an examination without acquiring the skills that the examination is intended to assess. Chapter 6 discusses the conclusions from the analysis and presents recomendations for further research.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

The problem investigated in this study arises from the researcher's observations of laboratory work by students admitted into the first year physics programme at Milton Margai Teachers College in Sierra Leone. The researcher became concerned about the students' difficulties because the scientific skills and knowledge required for such practical work should have been acquired in the secondary school physics programme in order to pass the G.C.E. "O" level physics practical examination. Data provided by physics teachers and students at three secondary schools in Freetown, Sierra Leone, establish a basis for interpreting students' difficulties in learning to carry out and make sense of the results of practical work. The data are interpreted in the light of a number of studies related to the importance of practical work in science instruction with reference to Renner's (1982) Learning Theories A and B. The analysis is based on what the teachers would like practicals to be, how they conduct physics practicals, constraints that inhibit their efforts to teach practicals the way they would like to, and the consequences students face due to the methods used to conduct physics practicals.

This study has investigated how students in three secondary schools in Sierra Leone are taught physics practicals. The researcher used field notes, tape recording, and interviews to collect data from three teachers and 116 students who were being prepared for the G.C.E. "O" level physics practical examination in June 1990. The data reveal that physics practicals are not used to illustrate physical principles that enhance understanding of the underlying concepts. Physics

practicals are being taught as a "product" of learning science, a product that is to be tested by the public examination which students take after two years of studying physics. It appears that the three physics teachers observed in this study have developed strategies for practical work that enable students to pass the practical examination in G.C.E. "O" level physics without developing the skills that the examination is intended to assess. At least some of the students who pass the examination are unable to demonstrate the intended laboratory skills in other contexts away from the examination setting.

The study reveals that teachers who participated in this study, like science educators in many parts of the world, believe that practicals will help students understand physics concepts better and hence promote liking for the subject. However, their views seem to be rhetorical. In reality, practicals are rarely done in the schools, and the few that are performed are focussed on enabling students to pass their formal examination. The few and limited practicals students performed in form V do not provide opportunities to develop practical skills in science or to test and extend their understanding of physical concepts. The central purpose is to give students opportunities to develop the skills required by the practical examination; secondary purposes include illustrating theory and giving students some sense of how physics relates to everyday life.

The approach teachers employed in teaching physics practicals seems intended to ensure that they complete the physics syllabus for the examination within the limited time at their disposal in forms IV and V. The poor economic situation in the country means that schools do not have funds to buy or replenish equipment. Lack of equipment limits the types of practicals students can do and increases the

need for teachers to present demonstrations instead. These demonstrations were performed at the expense of practical work students could have accomplished on their own. Lack of resources and equipment required students to do practical work in groups of five and limited these opportunities to ones for which materials and equipment were available.

The approach physics teachers in Sierra Leone employ in presenting theory and practical work is highly sequential and could be described as following a "traditional" perspective. First there is a theory, and then there is the practical work, and the two are quite separate. Perhaps unintentionally, teachers' actions have led students to believe that the basic role of practical work is to illustrate theory that they were to learn when it was presented by the teacher outside the context of practical work. Two of the most obvious pressures that sustain this traditional perspective are the extensive physics content within the curriculum and the emphasis on memory as a learning strategy for preparing to take an elaborate formal examination.

Illustration of theory is only one role of practical work, and some would argue that it is a minor role. There is potential for a dynamic and interactive relationship between theory and practical work, although it seems rarely realized in science classrooms. Renner (1982) worked to capture this potential by describing two learning theories (A and B) for which the essential difference is the timing of experience. By having practical experience precede presentation of theory, students have opportunities to gain access to their present conceptions of the topic and they have personal experiences from which concepts may be "invented." Such an approach acknowledges the role of experience in the learning process and

challenges the familiar tell-listen-remember sequence often associated with schooling.

As science education researchers and others have argued on numerous occasions, both theory presentation and practical work have important roles to play in effective physics teaching. In the context of an extensive curriculum content leading to a formal examination, theory presentation has traditionally held the "upper hand." This study shows that physics teachers in Sierra Leone are no exceptions to this rule. It also shows that they maintain this approach to physics teaching despite severe economic constraints that not only limit the availability of equipment and but also threaten their personal survival.

The data reported in this study were collected at a time of difficult economic circumstances in Sierra Leone. Teachers' salaries are low, relative to the cost of living, and their salaries are not paid regularly. As expected, these circumstances affect the teachers' work, yet it is impressive that their work continues at the observed levels. The observed practical activities can be interpreted as "constrained versions" of the teaching that might be observed in a stronger economic climate. More importantly, there is no reason to assume that higher or more regular salaries would cause the teachers' conduct of practical work to be different *in kind* from what was observed in this study.

Another point worth noting concerns the manner in which the physics practical examination is conducted. The setting of the exam reinforces the perspective that the practical is not as important as the theory, or even directly related to theory. As soon as students feel that one aspect is less important, then they begin to put less time and effort in that aspect with a view to reducing their workload. The manner in

which teachers teach suggests that theory is more important than practical work. When the physics teachers receive confidential instructions about the equipment and materials needed for the examination, they can make very close guesses about the questions that will appear in the examination. Since teachers can make such guesses every year, there is even less incentive for them to give time to practical activities during routine school work. If teachers do adapt their final lessons with students according to what they expect will appear on the examination, there is no intention here to criticize them for doing so. The situation presents a genuine dilemma for teaching, and those teachers who direct their students to likely practical work are continuing their sincere efforts to help students pass the examination in physics.

Implications for Practice and Research

When one studies an educational setting so dominated by formal examinations, implications drawn from the study must, inevitably, be cast in terms of the presence and absence of such examinations. As long as the teaching of physics in Sierra Leone continues to be dominated by pressures to pass formal examinations, we can expect little change from the situations apparent in the study's data. The teachers and their students can be commended for making the best of very difficult circumstances. The fact that each of the three teachers could quickly state changes that they would make if there were no examinations underlines the significance of the examination system in their work.

While the practical examination in physics persists, it could be helpful to formalize the sophisticated informal network that enables the teachers to gain

access to the equipment that will be required for the examination. One is even tempted to suggest that the last-minute coaching for the equipment required could be organized and co-ordinated, though this would hardly be seen in a favourable light by the Examinations Council. Formal workshops for teachers on the nature and purpose of practical work in physics could focus on ways of assisting students with the most common difficulties they face in interpreting instructions and manipulating equipment.

Within the constraints of the examination system, it could be very productive to develop a modified practical examination that did not involve the manipulation of equipment. Considerable insight into the nature of students' difficulties in learning to manipulate equipment might be gained by devising paper-and-pencil questions that test students' understanding of practical work. Experimental data could be reported for students to manipulate and interpret. Students could be asked to describe experimental procedures for exploring a particular set of concepts in physics. Such a modified examination would reduce the search for specific equipment and would eliminate the guessing done by teachers once the equipment list has arrived. This is not to suggest that practical work should receive even less time, but to note that the present circumstances generate unfortunate circumstances such as the initial observation that students cannot display practical skills required for the examination they have passed.

If there were no practical examination, then there would be a significant and genuine opportunity to re-think the relationship between theoretical and practical work in the teaching of physics. It is always tempting to suggest familiar in-service education strategies of workshops and short courses for teachers, and in the present

context of education in Sierra Leone, these would indeed be welcomed. However, there is little reason to assume that familiar strategies would address the more fundamental issue that has been raised in this study. The data from interviews of teachers and students and from observations of physics practical activities provide new insight into the issue of acquiring laboratory skills. The teachers use a familiar "theory first, practice later" sequence that suits the covering of content and preparation for the examinations. Although none of the teachers would suggest that understanding is not a major goal, the priority given to preparation for the practical examination signals in subtle but clear fashion to the students that long-term understanding is *not* an issue. The interpretation of the data in terms of the issue of sequence of instruction (tell, then verify vs. observe, then invent) suggests that the limited practical work done by physics students in Sierra Leone is unlikely to develop lasting skills that can be demonstrated in other, non-examination contexts. Thus students may well pass the examination that is intended to confirm the development of skills that they actually have not developed.

All three participating teachers complained about the limited time available to complete the G.C.E. "O" level physics syllabus. There are two possible explanations to this complaint. One explanation could be that there is too much subject matter to be covered in the physics syllabus. The other explanation could be that the teachers tend to regard each topic in the syllabus in isolation and hence teach topics separately instead of relating each topic to the other in order to understand and interpret physical phenomena better. The complaint about insufficient time to complete the physics syllabus signals the need to investigate whether the content of the physics syllabus is too extensive to be covered within the available two years.

This problem could be investigated with a questionnaire to science teachers in Sierra Leone and across West Africa. The findings of this investigation could lead either to maintaining the syllabus with curriculum guidelines or to reducing some of the content without affecting the standard students should achieve in order to study physics and related science subjects in the university.

Beyond the issue of the sheer size of the physics syllabus, there is a pressing need to write curriculum guidelines for the teaching of physics in secondary schools. Most teachers go through the G.C.E. "O" level syllabus treating one topic after another. Curriculum guidelines could spell out the aims of teaching each topic in physics. The guidelines could be arranged into core units and the time allocation for each unit could be suggested. This could act as a guide in helping teachers devote the appropriate amount of time to each unit, and would be particularly useful to teachers with limited backgrounds in physics. The curriculum guidelines could arrange the units in related sequence so that both teachers and students would be better able to see how each unit is related to the others. Each unit could recommend laboratory activities for students and demonstrations to be performed by teachers. It would be very interesting to prepare guidelines that provided clear sequences of topics followed by teaching suggestions organized into two strands illustrating Theory A and Theory B. This could be one small beginning in the complex task of introducing Theory B to teachers who are completely comfortable with approaches consistent with Theory A.

The interpretation of the teachers' activities and methods and of the difficulties students encountered in performing physics practicals was based on Renner's (1982) Learning Theories A and B. This calls for a study that will compare both

teaching approaches. From the description of the teaching approaches to both theories, it has been assumed that Theory B is a better approach than Theory A. The proposed study would serve to explore the significance of that assumption in the Sierra Leone context. It might be possible to recruit teachers and students for a special in-service teaching institute held during the July-September break so that it would not interfere with regular school work and teachers and students would not feel constrained to follow Theory A because of the pressure to cover the syllabus. Here physics teachers and students could attempt to explore the meaning of teaching approaches consistent with Theory B, in order to better understand the potential advantages and the accompanying difficulties.

On my return to M M T C in Freetown, my work will involve not only teaching physics to pre-service teachers but also teaching science methods and supervising teaching practice. One immediate consequence of the findings of this study will be the introduction of methods and activities in my teaching that will promote better understanding in my students, including a personal exploration of the value of teaching carried out as suggested by Theory B. These methods and activities could be developed and practiced during the students' pre-service teaching practicum. If secondary school students are to develop the practice of understanding physical concepts through activities and demonstrations that illustrate the concept, such practice should begin in the lower forms. This is where students from M M T C will assist greatly because they are being prepared to teach physics in the lower forms of secondary schools in Sierra Leone.

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Appendix A. OBSERVATIONS AND INTERVIEWS AT SCHOOL B

The following are transcriptions of the lessons and demonstrations conducted a day prior to practical classes, the interviews with two students, and an interview with teacher B. These lessons were meant to recapitulate theories previously studied while the demonstrations illustrated the activities involved in the practical work.

First Lesson and Demonstration before a Group Practical Class

[The teaching transcription that follows concerns the refractive index of light and how to measure the refractive index of a rectangular glass block.]

B: We are going to look at the laws of refraction of light and how to measure the refractive index of light for a given medium. [The teacher draws a standard diagram for light passing through a glass block, bending toward the normal on entering and away from the normal on leaving.] Let mm' represent the boundary between the media - air and glass.

NO represents the normal to the plane.

AO - the incident ray

OB - the refracted ray

i - the angle of incidence

r - the angle of refraction

The angle between the normal and the incident ray is called the angle of incidence. The angle between the normal and the refracted ray is called the angle of refraction. The laws are

1. The incident ray, the refracted ray and the normal all lie on the same plane.
2. The ratio of the sin i to sin r is a constant.

This constant is called the refractive index from one medium to another; it is usually designated by n. Now let us look at refraction from another point of view. Who can define refraction in terms of the velocity of light from one medium with respect to another medium?

S-101: [inaudible].

B: Anybody else? Yes.

S-102: The velocity of light from less dense medium is greater than the velocity of light in the other medium.

B: Given two media, the ratio of the speed of light in medium one to the speed of light in medium two is a constant. It can also be defined as

$$\frac{\text{THE VELOCITY OF LIGHT IN MEDIUM ONE}}{\text{THE VELOCITY OF LIGHT IN MEDIUM TWO}} = \text{CONSTANT.}$$

At the end of this class you should know how to find the refractive index of a glass block. I will also explain to you how to find the refractive index using the idea of real and apparent depth. What happens when an object is immersed in water?

S-103: It increases in size.

B: Is that true?

S-104: No.

B: What actually happens?

S-105: It appears to be nearer.

B: It appears to be raised. So therefore you have an apparent depth and a real depth. What is an apparent depth?

S-106: [inaudible].

B: The apparent depth of an object is the depth of the object as it appears raised. [Teacher B sketches on the blackboard to explain the difference between real and apparent depth.] What is the real depth?

S-107: The actual depth of the object.

B: We all know how to read the meniscus of liquids. What is the shape of the meniscus of water?

S-1O8: Concave.

[Teacher draws diagram of an object immersed in water in a beaker on the blackboard]

B: The real depth is the distance from the object to the lower part of the meniscus. The apparent depth is distance of the image of the object as it appears raised inside the liquid (in this case, inside the beaker). So we can also define refractive index as the ratio of the depth to the apparent depth. Having arrived at these definitions of refractive index, the most important point I want you to note is how to find the refractive index of glass. What we have to do in the lab is how to find the refractive index of glass. In this case what will be the first medium?

S-1O9: Air.

B: What will be the second medium?

S-1O10: Glass.

B: I will demonstrate it to you. In any experiment you do, it is important that you read the instructions first. A lot of students fail the G.C.E. "O" level practical examination because they do not know what to do. They are not patient enough to read the instructions well. You put a piece of drawing paper on the drawing board. The first step is to draw the outline of the rectangular glass block. The whole idea is for us to be able to define an incident ray and then find the angle of incidence, from which we find the angle of refraction.

Stick two pins on the incident ray. Light rays reflected on the pins will pass through the glass block. Then we search for the images of the two pins on the other side of the glass block. Come and watch the images on the other side of the glass block. Do you see the images of the pins? Then the next thing you do is to find by using two other pins the images of the first two pins so that they coincide. You will first of all see an image; then you will use it to locate the second image. After that, remove the glass block and join the points of the two searching pins so that they touch the lower side of the glass block outline.

Draw the normal through the glass block outline because the angles of incidence and refraction are measured from it. Join the two refracted points. The angles are now well defined.

This procedure is repeated for other angles of incidence and you will get resulting angles of refraction. You will have to do this in the lab; this is just a demonstration. As we go along in the lab I will explain to you better.

Now let me show you how we tabulate the results. For each angle of incidence, you will have an angle of refraction; then you will have sine of the angle of incidence and sine of the angle of refraction.

i	r	sin i	sin r	sin i sin r

You can then plot the values of sin i against sin r. If you are accurate enough you will get a straight line graph passing through the origin. If the graph is a straight line passing through the origin, what type of relation is that? [Teacher draws straight line graph on the blackboard.]

S-1O11: Direct relation.

B: Some students because of examination fright construct two separate tables. [Teacher illustrates by drawing two sample tables on the blackboard.] This is wrong. The table should be a composite one having all the values together. In all the experiments you do, make sure that you enter your readings in a composite table. The other important thing is in taking your readings, if for instance the angle of incidence is 32 degrees, it should be written as 32.0 degrees. Examiners penalize if you record your readings without the appropriate decimal points. The graph is a straight line because it is a direct variation, and so for all the values you take, the ratio of sin i to sin r will give you a constant value. The values for the quotient of the ratio of sin i to sin r may vary, but you will have to find the mean value of all the values. The next important thing is how to find the refractive index from graph. To find the refractive index you only need to find the slope of the graph. What is a slope?

S-1O12: The gradient.

B: The gradient in that graph will be the rise in the sin r axis divided by the corresponding increase in distance along the sin i axis. This will be the experiment you will be doing during our next practical.

Interviews with Two Students after a Practical Class

[The transcription of the interviews with the two students follows. The practical work was conducted a day after the demonstration. Students worked in groups of five. Each group performed the same practical—measurement of the refractive index of a rectangular glass block. After the practical class, teacher B identified the two students. These students were in different groups and were interviewed separately. The interview seeks to determine the students' understanding of the practical work done and their views about the practicals they do at school.]

Interview with First Student

JK: What was the practical about?

S1: The practical was about refractive index of a rectangular glass block.

JK: What were you required to investigate in this practical?

S1: We were required to calculate the angle of incidence and the angle of refraction.

JK: Did you get some readings?

S1: Yes, we got values like 28 degrees as the angle of incidence and 18 degrees as the angle of refraction. But they were not that accurate.

JK: How do you know that those values are not accurate?

S1: The size of the group does not permit one to take accurate readings because every other person in the group is pushing the other in order to watch for the image. These movements and pushing around the instrument does not permit the group to get accurate readings.

JK: Suppose you were working alone with the instruments, which area would you have problems with?

S1: My problem will be in finding the angle of refraction. Because if you stick pin one and two, you have to move to the other side to trace the image of the two pins before you stick the other two pins. It is difficult to determine the exact position of the images of the first two pins because they seem to be in a straight line with the searching pins from any point on the lower surface of the glass block. My problem was determining the exact position of the emergent ray in order to determine the angle of retraction.

JK: How are you going to analyse the values you have recorded?

S1: The values can only be analysed if tables of values are provided. The values should be entered in the tables and then calculated.

JK: Based on the practical that you have just done, how are you going to analyse your values in order to provide an answer to your investigation?

S1: It depends on the accuracy of the values.

JK: Suppose the values are accurate, how would you use them to provide an answer to your investigation?

S1: Then the value of the refractive index of air to glass will be given, then you will use the relationship of sin i divided by sin r.

JK: Can you think of another way of analyzing your data?

S1: That is the only way so far that I have been instructed in.

JK: Didn't your teacher talk about using a graph to analyse your data?

S1: Oh yes, you can use a graph. You will also be asked to draw a straight line graph.

JK: How will you get the refractive index of the glass block from the graph?

S1: I will have to go and look it up in my text.

JK: Will you have problems in plotting your values on the graph?

S1: No.

JK: Do you have any problems that you could discuss with me?

S1: We have got many difficulties. In the first place the number of glass blocks were not enough for the number of students in class. Secondly, we have been organized in groups of five and I had difficulty in understanding how to carry out the practical. Even some members of my group did not understand the aspects involved in the practical. Some members in the group did not take the work seriously because they attend private lessons after school; they cause noise in class to distract our attention.

JK: How did you get your values when you did not understand how to carry out the practical?

S1: A friend from another group came over to assist us. He is attending a private lesson.

JK: Thank you.

Interview with Second Student

JK: What was the practical about?

S2: It was about finding the refractive index of a rectangular glass block.

JK: What were you required to do in this practical?

S2: We were required to find the angle of refraction and the angle of incidence and hence the refractive index of the glass.

JK: Did you have any difficulties in performing the practical?

S2: No.

JK: So there is no aspect of the practical that you had problems with?

S2: None at all.

JK: What would you say about the facilities in the laboratory?

S2: I don't know much about the laboratory because I have just began using it.

JK: Didn't you do any practical work in form IV?

S2: No, it was just theory and it is only now that the class has started doing practical.

JK: Would you say that you had sufficient materials to work with during the practical?

S2: Well, we were in groups of five and there were enough materials for each group.

JK: Don't you think that it would have been advantageous to work in smaller groups?

S2: Well, some people say that two heads are better than one, so I think that working on groups of five is the best way.

JK: Don't you think that working in groups of two would have provided enough participation for every member of that group?

S2: Well, yes, there would have been more concentration, participation and speed in performing the practical. Working with four other students reduced the rate at which I worked.

JK: How does that reduce the rate at which you work?

S2: Because everybody has to write his results and it takes more time for everybody to write down the same data than if everybody was working on his own. Again, everybody wants to take part in carrying out the investigation which may lead to repeating things that a member of the group would have done. And I had to spend time explaining how to focus the images of the pins to my friends.

JK: Which areas did you have problems with in doing the practical?

S2: My problems were how to get the refractive ray and the angle of refraction. I thought that the emergent ray was the refracted ray and the angle which it makes with the normal on the other side of the glass block was the angle of refraction.

JK: How did you over come the problems?

S2: The teacher came over to explain to me, he did a demonstration for the group and after that I was able to carry out the experiment.

JK: How are you going to analyse the values you have recorded?

S2: I will have to divide the sine of the angle of incidence by the sine of the angle of refraction for each set of values.

JK: Then you will end up having four values but you only need a value for the refractive index for the glass block.

S2: Yes, I will also have to find the average of the values?

JK: Why do you have to find the average?

S2: I am not quite sure why the teacher say we should.

JK: Is there another method of finding the refractive index of the glass block from the same set of values you have recorded?

S2: None that I can think of now.

JK: Didn't your teacher talked about plotting a graph?

S2: Oh yes, he did talk about a straight line graph as another way of analyzing the values. The graph should be sin i against sin r.

JK: If you were to plot the graph of sin i against sin r, what difficulty will you have?

S2: If the graph is not a straight line, then I will know that there was something wrong with the values recorded.

JK: Suppose all your measurements were correctly taken and recorded.

S2: I don't think I will have problems because I have been plotting similar graphs in mathematics. Maybe the problem I will get is to let the line pass through all the points.

JK: Is it a rule that the line must pass through all the points?

S2: Well, the mathematics teacher says that the points should be on the line.

JK: Ask your physics and mathematics teachers when next you meet them about plotting of straight line graphs.

JK: Why do you do physics practicals?

S2: Because it part of the West African Examination Council (W.A.E.C.) physics examination. It is good to practice for the examination.

JK: Besides the physics examination, are there any other reasons why you do physics practical?

S2: No, I can't think of any, because I want to be a medical doctor and I don't think that will be necessary for me in the future.

JK: So medical doctors do not need to do physics practicals?

S2: No, they don't need to do physics practicals, it is only biology and chemistry practicals.

JK: Don't you see any relationship in the physics practicals you perform now to what you intend to study in the future?

S2: Well, no.

JK: So there is no relevance of physics practicals to your future career, other than passing the physics examination?

S2: Yes, we only do practicals to practice for the examination.

JK: Thank you.

Second Lesson/Demonstration prior to Demonstration in the Laboratory

[The transcription of the second lesson and demonstration follows. The theory was on minimum deviation of light through a triangular glass prism and the demonstration was on the measurement of the angle of minimum deviation.]

B: The points we discussed in our last lesson were

> The greater the refractive index of light, the greater the minimum deviation.
>
> For a triangular glass prism, the greater the angle of the prism, also called the refracting angle, the greater the deviation.
>
> The greater the refractive index of glass used, the greater the minimum deviation.

Assuming that you already know what we mean by deviation, minimum deviation, angle of deviation and angle of minimum deviation, today we are going to talk about total internal reflection and then look at the next experiment we shall do tomorrow. Tomorrow we are going to look at how the angle of incidence is related to the angle of deviation. What did we say the relation was? The greater the angle of incidence, the smaller the angle of deviation. But there is a particular point which is reached in which the angle of deviation increases instead of decreasing and that

point is what we call the minimum deviation; And the angle so formed is called the angle of minimum deviation.

We are now going to study another phenomenon under refraction of light called total internal reflection. What is total internal reflection?

S: [inaudible].

B: When does it occur?

S: When the object is upright.

B: That does not explain the physics of the matter.

S: It occurs when the angle of incidence is greater than the angle of refraction.

B: Is that correct?

S1: No.

S2: When the angle of incidence is greater than the critical angle.

S: When the angle in the less dense medium is greater than the critical angle.

B: Anybody else?

S: When the angle of incidence is greater than the critical angle.

B: That is one condition.

S: When the refracted angle is 90 degrees.

B: Is that condition adequate enough?

S: When the refracted angle is more than 90 degrees.

B: We have come across a new idea called critical angle. What is meant by critical angle? In order to explain what total internal reflection is, we need to know what critical angle is. Let us look at the conditions necessary for total internal reflection:

1. The angle of incidence should be greater than the critical angle.
2. Light must travel from a dense medium to a less dense medium.

Now we should define what critical angle is. What is meant by critical angle?

S: It is the angle of incidence for which the angle of refraction is 90 degrees.

B: Total internal reflection occurs when the incidence angle is greater than the critical angle. Now let us look at the relationship between refractive index and critical angle. [Teacher copies relationship as is given in the textbook on the blackboard].

B: How do you call this prism? [Teacher holds up a triangular glass prism in front of the class].

S: Triangular glass prism.

B: Today what we are going to do is to find the minimum deviation of light. The first thing you do is to

1. Pin the drawing paper to the drawing board and draw the outline of the prism with a sharp pencil.
2. Use two optical pins to define the angle of incidence for which we shall find the corresponding angle of refraction.

The two pins are used only to define the angle of incidence. Make sure that they are in a straight line. Don't touch them because I know that they are straight already. Now have a look through the other side of the prism.

S: They are not straight.

B: You are not looking at the top part of the pins, you should look at the bottom of the prism. Are they straight?

S: Yes.

B: 3. The next thing is to find the images of the two pins using a search pin. Now look at the other side of the prism to find the images. Do you see the images?

S: Yes.

B: How many do you see?

S: One.

S: Two.

B: One or two, how many should you see?

S: One.

B: One, the other one should overlap. It is possible for you to see two if you actually bend down but you have to be careful for parallax. The next thing you do is to take two other pins. What do you do with the other pins?

S: You put them in line.

S: You put them in line with the image.

B: Make sure they coincide with the image formed by those two pins. Then mark the positions of the two pins and remove, then join the points. These are the precautions that you should note.

1. Make sure that the pencil is sharp.
2. The pins must be sufficiently spaced.
3. Make sure that you draw thin and straight lines.

You then draw the normals at the incidence and refractive rays respectively. Use the protractor to draw the normals because they should be perpendicular to the face of the prism. Yesterday we said that the angle of deviation is formed by the original and final direction of the incidence and refracted rays, which means that you have to extrapolate them or extend them. One of our major problems for the next practical is that we don't have enough prisms. So make sure you come with one. You will have to repeat the whole procedure for another angle of incidence. After taking about three to five readings, you then tabulate your readings as follows.

Angle of incidence Angle of deviation

1.

2.

3.

4.

5.

[This demonstration was done on a smaller table which was placed about the centre of the classroom. The students gathered in a circle around the demonstration table, but students on the outer part of the circle could hardly hear what the teacher was saying. Some students climbed on the tables in order to see what the teacher was doing. A few of the students left the classroom because they could not hear or see what the teacher was saying and doing.]

Laboratory Demonstration

[The exercise scheduled for the practical was determination of the minimum deviation of a triangular glass prism. This turned out to be a demonstration because there was only one triangular glass prism for a class of about 50 students. The instructions and diagram were written on the blackboard for the students to copy in their physics practical books. The students read the instructions as the teacher proceeded with the demonstration. Students surrounded the teacher in order to see what he was doing. Some students left the laboratory because they could not see nor participate in the demonstration. Some values were written on the blackboard but no analysis of theme was done. Students copied the values without any instructions from the teacher.]

Interview with First Student after the Demonstration

JK: What did the activities involve?

S1: They were about the refractive index from air to glass in the form of a triangular glass prism.

JK: Were they about finding the minimum deviation of a triangular glass prism?

S1: Yes, it was about the minimum deviation.

JK: What were you required to observe during the activities?

S1: We were not told to observe anything. That was the beginning of the practical and I have still not understood what the teacher was doing.

JK: How did you call the activities the teacher performed in the laboratory?

S1: It was a practical because the materials were not sufficient; so in order to understand the basic principles the teacher used the only available prism to do the practical and we all stood around and watched.

JK: What part did you play in the activities?

S1: Nothing. Everything was done by the teacher.

JK: Will you say that you did a practical in the laboratory?

S1: No, but I have told you that the teacher did the work. It was a demonstration we watched.

JK: When will you say that you did a practical in the laboratory?

S1: When we work in groups and we do the work for our self and the teacher comes to look what we are doing. Sometimes he will have to show us what to do.

JK: If I provide you with similar materials, will you repeat what you observed in the laboratory?

S1: I cannot perform it alone because I have not understood how to go about it. It was the teacher who did everything and I copied from the blackboard. He talks about to extrapolate in order to get the angle of minimum deviation. I do not know what that means and I did not see him do it because everybody was crowded around the table

JK: What would you say is the major problem in performing practicals in this school?

S1: One problem is the availability of practical equipment. We should have done this practical individually but it was a demonstration by the teacher. Some students have to wait until others have seen the demonstration and they later go to see the demonstration. All the explanation was done by the teacher. If enough equipment were available , we should have worked in smaller groups or individually and that would have given us the opportunity to do the work ourselves.

JK: What will say about the number of students in class?

S1: The number of students in the class is large, about 45 in number and we have only one triangular glass prism.

JK: What will you say about sitting accommodation in the laboratory?

S1: We stand all through practicals or demonstrations. There are no stools or chairs in the laboratory. But I think the fault is coming from the central government; the government is not particular about educational problems in the country. It is not only in the laboratory that we lack sitting accommodation, even in the classroom. Not all of the students have sitting accommodation during class times. When I was in form IV, some boys brought chairs from their homes to school so that they will sit during class times. For some who did not bring chairs, they cluster around on few tables causing noise in class. If you have to stand for more than an hour it will be difficult to pay attention.

JK: Tell me, why do you do physics practicals?

S1: Physics practicals help students understand physics theory. Without practicals it will be difficult to understand the main things involved in physics. Some schools do general science which makes it difficult for the students to understand the basic principles. These schools only do the introductory aspects of physics, chemistry and biology. For students who do pure science like physics are able to perform practical and are able to understand the subject matter better. We also do physics practical to prepare us for the G.C.E. practical examination.

JK: Will the practicals that you have been doing prepare you adequately for the G.C.E. physics practical examination?

S1: It will never assist a student to pass his examination. In the first place the equipment for the practicals are not available in the country all round. Secondly, the maintenance system in this school is very low. There should have been more than one teacher supervising practicals in a class of our size, and to collect equipment after practicals which are to be kept in a safe place. Then this school should not have run into the problem of not having enough equipment. So with this regard if all sets of demonstrations are conducted by a teacher then it is very difficult for a student to understand and as such will not pass his examination.

JK: How then do you hope to pass the G.C.E. physics practical examination?

S1: It all depends on a matter of chance. At least there are some variation in the number of equipment. For light, the equipment available are very limited. On other areas like mechanics, we have some equipment that are enough, relatively greater in number than those in light. So if the examination is based on areas in which we have more equipment than those with very little or no equipment, we the students will attempt questions on areas with more equipment because we would have done a similar experiment before.

JK: Do you hope to do more practicals before the examination?

S1: Yes, but it will be difficult to do all the practicals we require for the examination now because there is not much time left for the exams.

JK: What type of practicals will you be performing then?

S1: The teacher will select some practicals that are important for the examination and we will have to do most of the practicals in past question papers. In fact as from next term we will be doing practicals only from past question papers.

JK: Why do you have to use past questions to prepare for the examination?

S1: Well,they sometimes draw the same question only that they will ask you to do different thing. During this time everybody will try to be present because exams will be approaching.

JK: Will this be the time that students take their practicals seriously?

S1: Yes. We will be doing practicals the teacher thinks are important.

JK: How will the teacher tell which practicals are important from those which are not?

S1: Sir, the examination council thinks that all the schools are equally equipped with practical materials. So as a result the council sends instructions to the schools for materials they will need for the practical. So with this regard, schools do practicals around these materials. Experiments that involve the use of these materials are what we will be doing.

JK: How come that you know about the instructions the examination council sends?

S1: When I was in form IV I heard students talking about it and please sir almost every school will get the instruction if they are doing physics practical.

JK: Will you agree with me if I suggest that some students pass physics practicals because they are guided before the examination and not because they understand physics.

S1: Yes sir. It is also true that some schools teach physics practical during the examination. Few of the teachers do help students during the practical examination. Not all students are able enough to grasp the physics questions because so many things are there that they do not understand. But in terms of the examination, if teachers find out that the percentage of students doing well in the examination are less than the percentage not doing well, they tend to assist their students so that they will pass. That is one of the reasons why this school has introduced the system that when a student has a high distinction, and wants to do his sixth form; he has to take a test in order to get admission.

JK: You seem to be well informed about the physics practical examination. How come you know these facts?

S1: Because our friends tell us.

JK: Have these friends taken the physics practical examination before.

S1: Yes, some did well in the examination but others did not.

JK: How do you find your teacher with regards to his teaching method?

S1: He is experienced in teaching physics. He is a graduate in physics. He taught us physics in form IV and now he is continuing with the class in form V. He hasn't got much problem with

us. Everything depends on the cooperation of the students and their attention paid in class because the teacher is very experienced.

JK: Thank you.

Interview with Second Student after the Demonstration

JK: What did you do in the lab?

S2: I was not present for the practical.

JK: Why were you not present?

S2: The place was too crowded and I could not see because I am short. Other students are taller than me and they were standing in front of me so I could not see.

JK: What was the teacher doing?

S2: He was demonstrating. The teacher did the demonstration. There wasn't enough equipment for the class to do practical. There was only one triangular glass prism. The teacher did all the talking and illustrations and even measured the values which we copied from the blackboard.

JK: Why did you leave the class?

S2: I could not concentrate, there was noise in the class and I had done it before.

JK: Where have you done it before?

S2: I have done it at my friend's home. He has a glass prism. We did it on our own at home.

JK: How will you describe the practicals that you do in school?

S2: Well, we do the theory first. We were suppose to be doing practicals in form IV, that is what I think and that is what everybody think. But teachers keep the practicals until when we are approaching the exams and we have to do everything in a hurry and there are no enough apparatus because of the country's economy. But the practicals we do are enough for us to pass the exams.

JK: Why do teachers keep the practicals until the examinations are approaching?

S2: Well, perhaps teachers think that we will remember better when it is nearer the examination. And also during this period we do practicals that the teacher considers very necessary for the examination.

[This student could not continue with the interview because his father came to collect him after school. The researcher made two appointments with this student in order to complete the interview but the student never turned up.]

Interview with Teacher B

[The transcribed interview with teacher B follows. The purpose was to get the teacher's views on physics practical work, to cross-check issues raised by students, to get an explanation on observations made in the classroom and the laboratory, and to discuss problems that affect the teaching of physics practicals in general.]

JK: How are students selected to study physics?

B: In this school students are selected on the basis of their performance in physics in the previous form. For instance when students get to form IV, senior teachers in the physics department look at records to see how well a student has been doing in physics. Of course not only in physics but in mathematics and other science subjects so that they could be streamed. In the area of physics, we look at the student's grade in the previous form.

JK: Why do students do physics practical?

B: In my mind I think they do these practicals so that they could better understand the concepts in physics. The practicals tie up students' theoretical knowledge with the understanding they get from playing with the materials in the lab. Without this I don't think there will be any wholistic understanding of the subject.

JK: How often do students do practicals?

B: On the average in this class which I teach, they do practicals once a week, but since we have a double period it covers both practical and theory that time. But we are handicapped by the

unavailability of materials. I would like to see the boys do practicals about three times a week at least because the practicals are so important that it makes the students understand the theoretical part better. I only conduct practicals once a week. Actually it should have been more than that but due to the unavailability of materials we cannot do otherwise.

JK: In one of the practicals students worked in groups of five and in the other practical you did a demonstration while students crowded around you. Would you like to explain the difference in methods?

B: Yes, exactly, that points to the fact that we do not have basic materials like rectangular glass blocks and triangular glass prisms. The demonstration was intended to give students an insight of what the practical involved so that when they go to other schools for extra work or find materials later on to do the practical themselves they will be able to do the practical better. It is very difficult for me right now to conduct a practical the way it should be conducted.

JK: Why do students go to other schools to do practicals?

B: Well, there may be personal reasons from the students, but I think that they go to other schools because they have more materials than our school. In these schools students do private work and they get the actual feel with the materials.

JK: Do you by chance know whether students pay for the private work in these schools?

B: I am pretty sure that they do pay because I could not imagine a teacher giving extra work to students as charity.

JK: With the few practicals your students have been doing, which aspects do they have difficulty with?

B: The difficulties they face sometime arise from their misunderstanding of the instructions. I believe some of them do not understand the instructions, they just jump on doing the practicals and so they have to go back and forth reading the instructions, whereas if they have understood the instructions earlier they should be able to do the practicals. And also you cannot remove the fact that some of them do not yet know the equipment we have in the lab, how they work and

how they should be set up, etc. They know the basic equipment but I wonder if they know how to use the micrometer screw gauge and the vernier caliper, for instance. They have studied how they operate and their uses in the lower forms but since we do not have any in the lab presently I doubt if they know how to use them. The students know about them theoretically but they may not have seen them. That is one of my fears about students studying physics up to form V in this school. Students should know about these basic instruments, how they work and how to use them.

JK: Could you explain what you mean by "they just jump on doing the practicals"?

B: Most times in the lab we use the same or similar materials and instruments to explain different concepts. So when students see the same materials and instruments they may think that they have been asked to do what they have been doing in class. Without reading the instructions properly they go on doing different things from what they have been asked to do.

JK: How often do students "just jump on doing the practicals"?

B: As often as they do practicals. I always tell them to read the instructions first before proceeding with any activity.

JK: How do you hope to get students to develop the practice of reading instructions before starting to work on practicals?

B: I hope to continue telling them to read the instructions before beginning any practical work.

JK: Besides the understanding of theory and getting grips on underlying concepts, do you conduct physics practicals with another intention?

B: Yes, I conduct physics practicals because I believe that by so doing the students will actually know that physics is not only a theoretical subject. In fact I feel that when I do practicals my main theme is to make sure that whatever the case may be, the students should know that the subject is a practical one and it should be applied within our environment. However, we should be able to explain concepts practically.

JK: Do you also conduct physics practicals with the intention of preparing students for the G.C.E. "O" level physics practical examination?

B: Yes. In fact that is one of the main reasons, especially when students get to form V. Even in form IV the practicals are also geared towards the examination but they are more general in nature with the intention of getting to become familiar with the use of the equipment and materials.

JK: If there were no public examination, would you conduct physics practicals differently?

B: Well, yes, to some extent. There are certain practicals which students could do at home but since I am constrained by the public examination I conduct practicals that students will need for the examination. So if there were no physics practical examination, I should have diversified the practicals we do in form V and would spend some time on how to interpret experimental results meaningfully.

JK: Then what type of practicals do students perform in form V?

B: Practicals that are geared towards the G.C.E. "O" level physics practical examination.

JK: How do students relate the theory taught in class to the practicals they do?

B: After the practicals they are expected to interpret the results by way of drawing graphs and interpreting the graphs. For instance they might be able to find out that they learnt in the theory class that the refractive index of glass is about 1.50, which is the theoretical value. If they perform an experiment in determining the refractive index of glass and they come up with a value close to that, then they know that they have proved what they learnt in theory. Through practicals students can also find out that different glass materials have different refractive indices, which will prove the point that the speed of light varies in different materials.

JK: How would you describe the G.C.E. "O"level physics practical examination?

B: From the G.C.E. "O" level physics syllabus, one will see that the examination tests whether the students have been adequately prepared to study physics at the university or college. It still remains for us teachers to show the students that the knowledge of physics has to be acquired not only for the examination or to go to university but could be useful to their environment.

JK: I observed that there were not enough instruments and materials for students to work with. How do you cope with this shortage, especially when you conduct the G.C.E. "O" level physics practical examination?

B: At the nick of time for the physics practical examination, I ask the principal to buy instruments and materials that are available locally. Others that cannot be bought locally can be got either from other schools or the university and college.

JK: How do you know which instruments and materials the principal should buy or get from other schools or university or college?

B: The examination council sends confidential instructions of materials and instruments required for the examination to the principal of the school. The principal in turn hands over the instructions to the teacher teaching physics in form V. The teacher then checks for the instruments and materials he has in his lab and those he does not have. It is from the confidential instructions that we know which materials and instruments to either buy or borrow.

JK: Is the shortage of instruments common to all the schools doing physics?

B: Yes. Some schools may have some materials and instruments. I am sure no school in the Western Area has everything in the laboratory. Some schools do not have any instrument in their laboratories.

JK: Does that mean that students in these schools do not do practicals in their regular classes?

B: Yes. In some of these schools teacher teach theory all the time because of the unavailability of instruments and materials.

JK: How then are students prepared for the G.C.E. "O" level physics practical examination?

B: In most of the schools practical classes are conducted only a few weeks before the examination. Students are drilled for the practical examination after teachers have seen the instructions required for the practical examination.

JK: Could you suggest reasons why some students that pass the G.C.E. "O" level physics examination do not perform well in practicals at college?

B: The process of acquiring knowledge in physics is not discrete but continuous. One has to start from the basic, then to the complex. If you have learnt how to use an instrument, perhaps doing a practical might only involve a fraction of the knowledge you know about the instrument to get the result. So if you do not get the fundamentals earlier then you will eventually end up not being able to do much in practicals. If you have a crash program of practicals in schools so that the students can answer the practical questions, then they will not get the understanding of how to do practicals. This is why students face a lot difficulties when they go to college. So if you learn to do an experiment so that you can answer a particular question in the exams, that does not necessary mean that you have actually acquired the necessary skills. The most important point is that students must acquire the fundamental skills and be able to use them later; otherwise students might end up passing the exams with good grades but unable to perform similar experiments at a later date.

JK: Do you think that diagrams assist students to follow instructions or do they create problems in practical physics?

B: They help a lot because in physics as in biology, chemistry, and geography, diagrams play a very good role. Our students face a lot of difficulties trying to interpret things in English; if they have diagrams that represent concepts, then that will assist understanding. For instance, diagrams in electricity representing rheostat, key, ammeter, and voltmeter in practicals go a long way to help students follow instructions. If instructions are only written in English without diagrams, then students will be faced with greater problems. Diagrams go a long way to assist students to follow instructions and to conceptualize what they are required to investigate in practicals.

JK: If you were asked to prepare the G.C.E. "O" level physics practical examination, what type of questions will you set?

B: I will set short-answer questions and a practical, of course. But the practical will involve short procedures that will require students to write down their results for every step accomplished and

finally the students will use the results to do an investigation. The present practical questions include all the necessary instructions but these instructions should be in steps so that the student will know what he is required to do and measure. The instructions should involve short steps written in sequence so that students can easily follow.

JK: What are your views about physics teachers in general?

B: Physics teachers in Sierra Leone find it difficult to work in an environment where they do not have visual aids. Teachers face numerous problems, for example, the problem of getting equipment and materials and funds to buy materials that could be got locally. The majority of physics teachers want to leave teaching for other professions. Teaching physics is very interesting but if the conditions under which you are working are not favorable as compared to other jobs, then you end up not doing much. Physics teachers do not get job satisfaction because of the prevailing conditions in the schools of not having materials and equipment to work with and getting salary at the end of the month is not certain. Physics teachers should be more receptive to their students because we are losing a lot of them. The long term effect will be that there will be no students studying physics at the university and college. If physics teachers impart the necessary fundamentals to their students so that they become well grounded in physics in the secondary schools, then students will build on that foundation when they go to university or college. Physics teachers are very few, and teachers have to do part-time teaching in other schools so that these schools get the services of a physics teacher. A few engineers waiting for jobs are employed to teach physics in some schools. These engineers face a lot of problems in the classroom because they were not trained to teach physics.

Appendix B. W.A.E.C. PHYSICS PRACTICAL EXAM, JUNE 1990

The first four pages that follow are the instructions sent to schools for Alternative A of the West African Examinations Council Practical Examination in Physics in June 1990. The subsequent five pages contain the examination instructions distributed to candidates.

431/1/X June
S.C./G.C.E. 1990
PHYSICS 1
Practical
ALTERNATIVE A
INSTRUCTIONS
CONFIDENTIAL

A

WEST AFRICAN EXAMINATIONS COUNCIL

School Certificate and G.C.E.

PHYSICS 1

June 1990 PRACTICAL

Alternative A

Instructions to Supervisors

1. Great care should be taken to ensure that the information given below does not reach the candidates either directly or indirectly.

APPARATUS

2. In addition to the usual equipment of a Physics laboratory each candidate will require the following:

General

Mathematical tables;
Graph paper;
Geometrical instruments.

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Question 1

60° Triangular glass prism
Drawing board
Four drawing pins
Four optical pins
Two drawing sheets
Protractor
30 cm ruler

Question 2

2 V accumulator
One centre-zero galvanometer
One metre bridge
105 cm of bare constantan wire gauge s.w.g. 26 or 28
2 Ω standard resistor labelled R
Jockey
One plug key
Eight connecting wires
One crocodile clip

Question 3

A pair of vernier callipers
Weighing balance reading up to 0.10 g
About 150 ml of water in a beaker

One 250 ml glass beaker or a glass beaker of less capacity. A strip of graph paper of width 0.6 cm and length 6.0 cm graduated in cm. The strip should be marked clearly from 0–5 cm in interval of 1.0 cm. The strip should be attached carefully to the side of the beaker with gum or sellotape such that the depth of the liquid in the beaker can be measured directly.

CONDUCTING THE PRACTICAL PHYSICS TEST

3. The purpose of the practical Physics test is to find out whether the candidates can carry out simple practical work themselves. A candidate may sometimes be unable to show his/her practical ability through failure to understand some point in the theory of an experiment. In order to overcome this difficulty, you are requested to give (or to allow the Physics Teacher to give) a hint to a candidate who is unable to proceed.

4. The following regulations must be strictly adhered to.

(*a*) No hint may be announced to the candidates as a whole.

(*b*) A candidate who is unable to proceed and requires assistance must come up to you and state his or her difficulty. The candidates should be told that the Examiner will be informed of any assistance given in this way.

(*c*) A note must be made, on the Report Form, of any assistance given to any candidate, with the name and index number of the candidate.

5. It is suggested that the following announcement be made to the candidates at the beginning of the examination.

'The Examiners do not want you to waste your time because you cannot proceed with an experiment. Any candidate, therefore, who cannot continue with his/her experiment after he/she has spent a long time at it, may come to me and ask for help. I shall report to the Examiner any help given in this way, and some marks may be lost for the help.'

SUPERVISOR'S REPORT FORM

6. Supervisor's Report Forms are provided separately, on which you are requested to:

(*a*) supply detailed information about the apparatus where necessary

(*b*) report on any particular difficulties experienced by any candidate, especially if the Examiner would be unable to discover these from the written answers.

7. The candidates will be instructed not to write out a detailed description of the apparatus, but you, or the Physics Teacher, should state on the Report Form any difficulties which were experienced with the apparatus or any departure from the specified items which could not be avoided. In cases where several sets of apparatus are provided for a question and specific information about the apparatus is required by the Examiner, each piece of apparatus about which the information is required, and which may differ slightly for different candidates, must be clearly marked with letters A, B, C, etc., and the corresponding information must be clearly reported, showing which apparatus was supplied to which candidate. The candidates will be instructed to record these letters in their answer books.

8. The Report Form is also to be used for reporting on any assistance given to the candidates under the regulations explained in 4 above.

9. The Report Form should be signed by the Supervisor and by the person responsible for preparing the apparatus.

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PHYSICS 1
Practical
ALTERNATIVE A
$2\frac{3}{4}$ hours

A

WEST AFRICAN EXAMINATIONS COUNCIL

School Certificate and G.C.E.

PHYSICS 1

June 1990 PRACTICAL $2\frac{3}{4}$ hours

Alternative A

Answer two *questions* only.

You are required to record your observations as soon as they are made. The observations and any mathematical working and answers to questions should be written in your answer book; scrap paper must not be used. Attach your graphs to your answer book. You are not expected to copy out your work again neatly. The record may be kept in pencil, provided it can be read clearly. If any piece of the apparatus provided has a label with a letter on it, this letter must be recorded in your answer book in order that the Examiner may identify which set of apparatus you used.

Neither a detailed description of the apparatus nor a full account of the method of carrying out the experiments is required. You should, however, note any special precautions you have taken and it must be clear (by diagrams or otherwise) exactly what the readings mean and how they were obtained.

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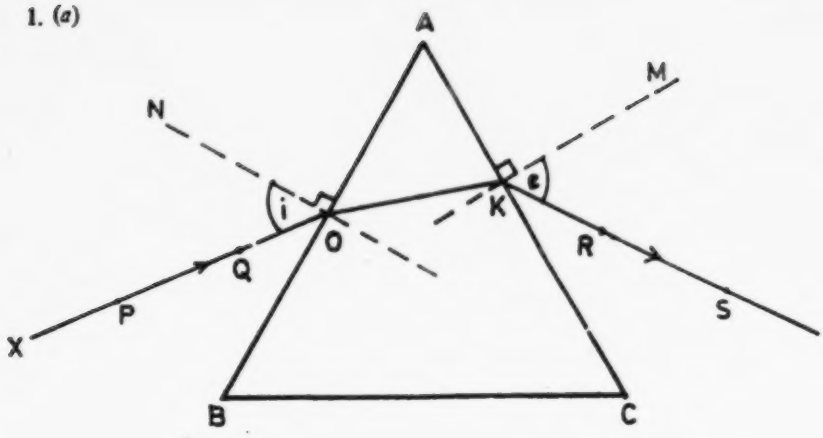
1. (*a*)



Place the triangular glass prism on the drawing paper and draw the outline *ABC* as shown above. Remove the prism. Mark a point *O* along *AB* and draw *ON* perpendicular to *AB*. Draw *OX* such that the angle of incidence *i* is 32°. Fix one pin at *P* and another at *Q* along *XO*. Replace the prism.

Fix one pin at *R* and another at *S* so that they are in a straight line with the pins at *P* and *Q* when viewed through the prism. Remove the pins and the prism. Join *RS* and produce it to meet *AC* at *K*. Draw the normal *KM* at *K* and measure the angle of emergence *e*.

Repeat the experiment four more times with values of $i = 37°, 42°, 47°$ and $52°$ and measure the corresponding values of *e*. Tabulate your readings. Plot the graph of $(i-e)$ on the vertical axis and *i* on the horizontal axis. Draw a smooth curve through the points. Determine from your graph the value *x* of the angle of incidence at which the graph intersects the horizontal axis. Calculate the value of 2 sin *x*. Using your graph, determine the value of $(i-e)$ when $i = 38°$ and hence find the value of *e*.

[24 marks]

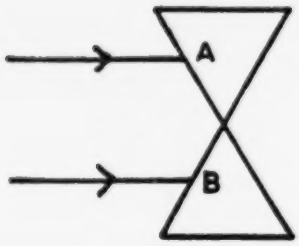
(*b*) (i) With the aid of a diagram, show one practical application of a right-angled triangular glass prism.

[2 marks]

(ii) A ray of light is incident on a glass block at an angle of 55°, what will be the angle of refraction if the refractive index of glass is 1.5 ?

[2 marks]

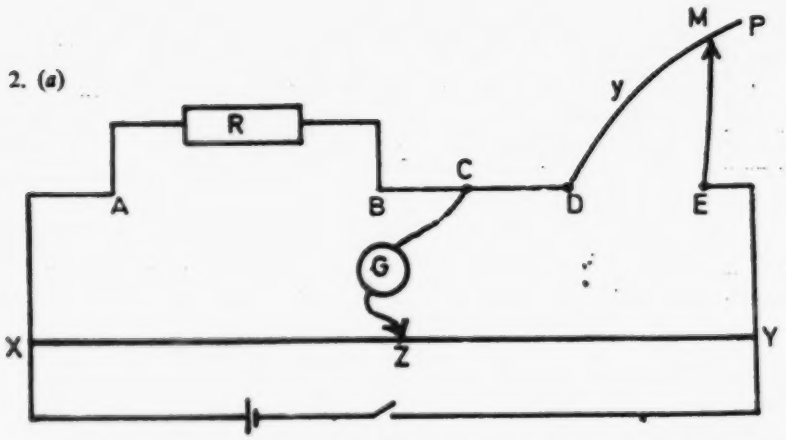
(iii)



The diagram above shows two glass prisms placed apex to apex. Two parallel rays of light meet the two prisms as shown. Copy the diagram and trace the paths of the rays through the prisms and beyond.

[2 marks]

2. (*a*)



Connect up the metre bridge as shown above. The resistor R is a standard resistor carrying a label of the value of its resistance and DP is a bare resistance wire about 105 cm long. Connect the crocodile clip at a point M on the bare resistance wire such that $DM = y = 20.0$ cm and find the balance point Z on the metre bridge. Record the length XZ of the metre bridge wire. Repeat the process for $y = 40$, 60, 75 and 100 cm. Plot a graph of y along the vertical axis and $\frac{100}{XZ}$ along the horizontal axis starting both scales from the origin. Determine the slope of the graph and the value of y when $\frac{100}{XZ} = 0$. State two necessary precautions.

[24 marks]

Turn over

(*b*) (i) If in this experiment, R is balanced against length y of the wire DP and a student wrote down the equation

$$\frac{R}{y} = \frac{XZ}{YZ}$$

Would he be wrong ? Explain your answer.

[2 marks]

(ii) Draw and label a circuit other than the Wheatstone/Metre bridge circuit which can be used to determine the resistance of a given conductor.

[2 marks]

(iii) Write an equation showing the relationship between the resistance R, the length L and the area of cross-section A of a conductor and state the name given to the constant K in the equation.

[2 marks]

3. (*a*) You are provided with an empty beaker which carries a linear scale. Use the pair of vernier callipers provided to determine the internal diameter D of the beaker. Also determine and record the area of cross-section A (in cm^2) of the beaker from the expression,

$$A = \frac{\pi D^2}{4}$$

Now weigh the empty beaker and record the mass Mo. Pour some water into the beaker to a depth h such that h is about 0.5 cm. Measure and record the value of h accurately. Weigh the beaker and its content together and record their total mass M. Determine and record the value Ah, the product of the cross-sectional area and the depth of water in the beaker. Repeat the procedure with h = 1.0 cm, 1.5 cm and 2.5 cm. Record the mass M of the beaker and its contents. In each case, record the value of h accurately and determine the value of Ah. Tabulate your readings. Plot a graph of M on the vertical axis and Ah on the horizontal axis. Determine and record the:

slope of the graph;
intercept on the vertical axis.

State two precautions you have taken to obtain good results.

[24 marks]

(*b*) (i) Obtain an expression to show the relationship between M, Mo, A, h and the density of water d in this experiment.

[2 marks]

(ii) Use your graph to determine the mass of water of depth 4.0 cm in the beaker.

[2 marks]

(iii) If a density bottle of mass 60 g weighs 80 g when completely filled with water and 90 g when completely filled with a liquid, calculate the relative density of the liquid.

[2 marks]

Vita

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THE COMPLEXITIES OF PRACTICAL WORK IN PHYSICS TEACHING: A CASE STUDY OF THREE SECONDARY SCHOOLS IN SIERRA LEONE

by

Jonathan N. Keister

A thesis submitted to the Faculty of Education

in conformity with the requirements for

the degree of Master of Education

Queen's University

Kingston, Ontario, Canada

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Abstract

This study examines the teaching of physics practical skills in secondary schools in Sierra Leone. The study develops from the researcher's observations of laboratory work by first-year physics students at Milton Margai Teachers College. Many students could not demonstrate basic science laboratory skills and knowledge required to perform simple physics practicals. Such basic skills and knowledge should have been acquired in the secondary school physics programme in order to succeed in the General Certificate of Education Ordinary (G.C.E. "O") level physics practical examination. This study shows that students fail to acquire basic science laboratory skills because their teachers are unable to conduct physics practicals as they would like to, and this has inevitable consequences for their students' learning.

The study involves three classes (116 students, 20 female and 96 male, between the ages of 16 and 18) and three physics teachers (1 female and 2 male) at three secondary schools in Freetown, Sierra Leone. The students were studying physics in form V in preparation for the G.C.E. "O" level physics practical examination in June 1990. The data include observations of four physics lessons, five physics practical classes, and one laboratory demonstration, as well as nine interviews—three with the teachers and six with students). Data were collected over a two-month period in October and November, 1989. The data are analyzed and discussed in light of the teaching methods and barriers that seem to inhibit students' understanding of scientific concepts.

The study suggests several reasons why students fail to acquire basic scientific laboratory skills and knowledge. The teaching of physics is compartmentalized into "theory" and "practical," and these are taught as separate

and unrelated entities. The formal examination system, which dominates the thinking of teachers and students alike, promotes this division and strongly influences the teaching methods employed in the schools.

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This thesis is dedicated to my deceased father, Jonathan S. Keister.

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CHAPTER 1

INTRODUCTION TO THE STUDY

This study is a qualitative inquiry into the teaching of practical or laboratory skills in secondary schools in Sierra Leone. In addition to this specific focus, for which data were collected in three schools in Freetown, the study also examines the issue of the relationship between direct experiences with physical phenomena in laboratory settings and formal classroom instruction in the theories of physics.

Significant emphasis is placed on practical work in the secondary schools physics programme in Sierra Leone. As in many other countries, personal laboratory experiences are judged to be an important part of the teaching of physics. In English-speaking West Africa, the physics practical is considered so important that it forms part of the formal examination in physics. In Sierra Leone, students in secondary schools begin studying physics as a separate science subject in form IV, after a three-year course in general science that includes biology, chemistry and physics. At the end of form V, the General Certificate of Education Ordinary Level (G.C.E. "O" level) examinations are written in five to nine different subjects. To be awarded a "pass" grade in physics, students must pass both the practical and the theory papers.

In order to pass the practical examination, students require an understanding of basic principles and applications of physics. In addition, students are expected to have developed scientific skills and attitudes that will serve as prerequisites for later learning of more advanced skills of scientific investigation at the university or

teachers' college. To pass the practical paper in the G.C.E. "O" level physics examination, students should possess the following basic scientific skills:

1. Assemble apparatus when instructions and sketches or circuit diagrams are provided.
2. Measure physical quantities within a given level of precision.
3. Identify possible causes of errors in instrument measurements.
4. Record and describe observations accurately.
5. Interpret recorded data from an experiment.
6. Represent data graphically.
7. Make predictions from linear graphs.

Some of the students who pass the G.C.E. "O" level physics go on to study physics for three years at Milton Margai Teachers College (M M T C) to become qualified as physics teachers for the lower forms of secondary schools. In the first year students take an introductory course in physics that involves revision of the G.C.E. "O" level work in physics and basic higher level physics.

Immediately prior to my full-time study for the M.Ed. degree at Queen's University, I taught physics at M M T C for four years (1984-88). During those years I observed that students admitted into the physics programme were unable to perform apparently simple aspects of physics practical work, even though they passed the G.C.E. "O" level physics. The difficulties with practical work demonstrated by many students over a period of several years provided the initial question for this inquiry into the preparation for practical work experienced by students in secondary schools.

Purpose of the Study

The purpose of this study is to document and analyse teachers' and students' activities during physics practicals in order to gain critical insights into the following questions:

1. Why do students not acquire the expected practical skills?
2. How do theory and practice interact in the context of teaching for the practical examination in physics?

Illustration of the Problem

The following examples illustrate some of the difficulties students display during physics practicals. Most students seem unable to connect simple electric circuits, even when instructions for the connections are given and the arrangement of the apparatus is illustrated by means of circuit diagrams. The apparatus to be connected in the circuits may include batteries, rheostat, ammeter, key, resistors, voltmeter, and insulated copper connecting wire. Few students could connect the rheostat properly in order to vary the current flowing through a circuit. The majority of students knew how to connect the ammeter in the circuit but few could do the same for the voltmeter. Most students had difficulty connecting resistors in parallel, although they could connect them in series. The students also had difficulty connecting ammeters and voltmeters correctly in relation to the terminals of the batteries in the circuit.

Students also displayed difficulties in optics, particularly in following instructions accompanied by ray diagrams. Instructions were given on how to set up a plane mirror so that the reflected rays could be traced with optical pins. Instructions were also given on how to trace refracted rays from rectangular glass blocks using optical pins. The ray diagrams showed the direction rays travelled and positions to fix optical pins. Students' inability to trace reflected and refracted rays meant that they could not measure angles of reflection and refraction.

Most students could not determine the appropriate level of accuracy to record values from a meter rule or a micrometer screw gauge. They recorded readings from both instruments with the same number of decimal places, even though the instruments measure at different levels of precision. This inability to record data to the correct degree of accuracy was also illustrated in recording readings from ammeters, voltmeters, and thermometers.

Another example of students' inability in physics practicals involved activities with a simple pendulum. Students are usually required to hang the pendulum from a fixed support, measure a specific length of the pendulum, and give the pendulum a small displacement so that it will oscillate. The students are asked to determine how long it takes for the pendulum to make a given number of oscillations and to find the periodic time for a given length of the pendulum. Most students could not distinguish between the frequency of oscillations and the period of a single oscillation.

A final example prevalent in physics practicals but strongly related to students' mathematical competence is, quite simply, they cannot plot graphs of values obtained from experiments. The difficulty seems related to their inability to determine

the scales to be used on the axes of the graphs. Also, few students could determine the gradient from a graph and make appropriate inferences.

These examples suggest that there is good reason to inquire into the teaching and learning associated with practical work in physics at the secondary school level in Sierra Leone. It is not the purpose of this study to attempt an explanation of how students pass an examination but later lack the practical skills it requires. This study addresses the broader issue of how practical activities are conducted in schools, including the relationship between practical work and instruction in theory, as summarized in these questions:

1. How, if at all, do practical activities contribute to understanding physics?
2. How do practical activities contribute to individuals' development of specific skills for performing laboratory experiments?

Outline of the Study

To collect data relevant to these questions, physics lessons and practicals were observed and interviews were conducted with teachers and students. The interviews and two physics lessons and demonstrations were tape-recorded and extensive field notes were made. The data were provided by three secondary schools in Freetown, Sierra Leone. Participants in the study were three physics teachers and 116 form V science students who were being prepared for the June 1990 physics practical examination.

The data are analysed by listing the reasons teachers gave for conducting physics practicals and comparing them to what the researcher observed during

practicals. The students' impressions about the place of physics practicals in the study of physics and their reasons for doing physics practicals are also analysed. Included in the analysis is an account of how the G.C.E. "O" level physics practical examination affects the methods used to teach physics in secondary schools in Sierra Leone. Excerpts from the interview data with students illustrate how they were unable to apply theory to practice and suggest that practical work does not improve their understanding of physics concepts.

This study shows that the practical portion of the G.C.E. "O" level examination in physics strongly influences the manner in which physics is taught in the schools. The teaching of physics is compartmentalized into "theory" and "practical"; content and concepts are taught in theory classes, while in the laboratory students perform practical activities the results of which are already known to be correct, that is, they verfify known facts in physics. These are the types of practicals that are required for the examination. The practicals students perform do not necessarily follow from the theory that has been taught. Theory is first taught in form IV and the practicals are performed later, in form V, so that teachers will have enough time to finish the theory. Students are drilled several months before the examination on the type of practical work the teachers expect will be asked in the examination. This intensive and specific "coaching" to pass the examination indicates the extreme importance of the examination and also suggests how it becomes possible for students to pass the G.C.E. "O" level physics examination and still exhibit inadequacies in practical skills and the interpretation of laboratory data.

Chapter 2 presents the introduction to the research setting and describes the participating schools and teachers. The section on the introduction to the research

setting describes the examination system, the physics examination, the physics practical examination questions. Chapter 3 examines literature related to the role of practical work in the teaching and learning of physics and describes the research methods. The section on research methods describes the design for data collection, participants in the study and preparation of data for analysis. Chapter 4 presents selections from the data supplied by the teachers and students who participated in the study, and these data are analysed and interpreted in Chapter 5. Conclusions are drawn in Chapter 6, and recommendations are made to physics teachers and students in Sierra Leone. Recommendations for further research are included. Appendix A contains transcriptions of the data collected at School B, including interviews with the teacher and students and observations of lessons before practicals, to give the reader access to the nature of the complete data set. Appendix B contains the question paper for the G.C.E. "O" level physics practical examination in June 1990, to illustrate the types of practical skills tested in this examination.

CHAPTER 2

INTRODUCTION TO THE RESEARCH SETTING AND PARTICIPANTS

This chapter introduces the reader to the context of education in Sierra Leone and to the particular schools and teachers who contributed to the data collection process.

The Examination System in Secondary Education in Sierra Leone

The present system of formal education in Sierra Leone was derived from the British educational system during the colonial period (1772-1961). Movement of students from secondary schools to the university and teachers colleges is determined by public examinations (Johnson, 1981). The public examinations are the General Certificate of Education Ordinary (G.C.E. "O") and the Advanced (G.C.E. "A") levels, which are conducted by the West African Examination Council (W.A.E.C.). Students are evaluated on a nine-point scale at the "O" level standard: 1 indicates distinction, while 7, 8, and 9 indicate failure. At the "A" level standard students are evaluated on a seven-letter scale on which A is excellent, F is failure and S is a subsidiary pass. Students take the G.C.E. "O" level at the end of form V (i.e., 16 to 18 year-olds). Students who obtain passes with distinctions and credits in five or more subjects can either do an additional two years pre-university course ("A" level) in three of the subjects passed at "O" level or enter one of the two university colleges. Students who pass in four subjects at "O" level standard can go to Milton Margai Teachers College where they are trained as teachers for the lower forms (one to three) in the secondary schools.

Students who study physics, chemistry, biology and agriculture up to forms five and six receive instruction on both the theory and practical aspects of the subjects. Some of the objectives of practical work are to enable the students to understand theoretical concepts through laboratory activities, to become familiar with apparatus relevant to the subjects at that level, and to provide training in performing experiments.

The West African Examination Council physics syllabus is the operational syllabus in use in secondary schools that offer physics in their curriculum (General Certificate of Education O and A Level Syllabuses: 1985-88, 1984). The G.C.E. "O" level physics examination conducted by the W.A.E.C. consists of two separate papers. Paper 1 is a practical test lasting two and three-quarter hours and containing three questions, of which candidates are to answer any two to score a total of 60 marks. Each question has two parts: part A involves performing an experiment, which carries 24 marks, while part B consists of three short-answer questions that are related to the experiment and carry 6 marks. (See Appendix B.) Paper 2 lasts for a total of two and one-half hours. Section A contains 60 multiple-choice items lasting one and one-half hours and carrying 60 marks; Section B comprises four essay-type questions, of which candidates must answer any three; this section lasts one hour and also carries 60 marks.

The Physics Practical Examination

Physics practical examinations are usually conducted in the laboratories of schools that prepare students for the G.C.E. "O" level examination. Senior physics teachers and assistants at these schools usually act as invigilators. About two

weeks before the practical examination, the senior physics teacher receives an instruction sheet containing a list of materials and equipment to be assembled for the examination. (See Appendix B.) These materials and equipment may include rectangular glass blocks, converging lenses, optical pins, ammeters, voltmeters (with specifications), meter rules, pendulum bobs, and stopwatches. The senior teacher arranges the materials and equipment in accordance with the instructions given on the instructional sheet.

Students are examined in groups, the size depending on the quantity of materials and equipment available and on the size of the laboratory. Each student receives a question paper and reads through the questions, selecting two questions he wants to answer and then informing the invigilator, who matches every student in the group to a question so that no two students will be working on the same equipment at the same time.

Each question gives detailed instructions and a description of how to proceed with each experiment. In some instances, the questions are accompanied by sketches of how to set up the materials and instruments or circuit diagrams for questions on electricity (see appendix B). Each student works on a separate table on which he will find all the necessary materials and equipment. The questions pose novel problems for students; the skills required to solve these problems should have been developed through the experiences students had in performing physics practicals in schools.

Generally, every question requires plotting graphs and determining values from the graphs.(see appendix B) Students are evaluated on the consistency of their values, on their ability to plot graphs, and on their ability to determine gradients and

make inferences from graphs. Students are not evaluated on their ability to set up the apparatus. It is believed that students can only record values if they are capable of setting up the apparatus. Invigilators are permitted to assist students in areas of procedure if students encounter difficulties in setting up the apparatus but such assistance must be recorded on the students' answer sheet and marks will be deducted for the assistance given.

The Participating Schools and Teachers

This section describes the schools, the laboratories and their facilities, and briefly introduces the three teachers who participated in the study. To preserve anonymity, the schools and teachers are referred to as schools A, B, and C, and teachers A, B, and C respectively. Regular school hours begin in all three schools at 8:30 a.m. and end at 2:30 p.m. with a 30-minute lunch break at 12:00. Each period in the school timetable lasts 40 minutes.

School A

This is a secondary school for girls with a student population of about 800. The curriculum up to form V includes the sciences, arts, humanities, and vocational (typing, shorthand, etc.) subjects. This school has a female administrator as head, and about 75% of the teaching staff are female. Physics in forms IV and V is taught by a female teacher. The school also employs a laboratory technician who studied physics up to form V but has no training as a laboratory technician. He has worked in this school for four years, and his duties involve preparing and arranging

instruments and materials for practical classes and cleaning the laboratory after practicals. He also assists students with their practical work.

School A has a well-built laboratory with some facilities to teach physics up to form VI. The materials and instruments are sufficient to conduct practicals and demonstrations at every level. All the instruments are kept in a preparatory room within the laboratory. However, a few basic materials such as stopwatches, meter rules, rectangular glass blocks, triangular glass prisms, ammeters, voltmeters, low-value standard resistors and rheostats are limited in quantity. The school has a separate building with laboratories for chemistry, biology, and physics. Physics classes are held in the physics laboratory which has three long benches with gas taps, a long concrete bench along the side with four water taps, a demonstration bench with water and gas taps, a blackboard, and enough stools for every student. Three students can conveniently work on each of the benches. The laboratory is well ventilated, tiled and clean, with a bright and spacious appearance.

Practical classes for form V are held in the afternoons after lunch break during a double period (80 minutes). Before practicals begin, the teacher gives a detail explanation of the procedures, theory, measurements, calculations and precautions that should be observed in carrying out the work. There were 20 students in form V science and each one worked alone with a set of apparatus. More than one experiment is set up during each practical period, to ensure that each student works on an experiment each time. The two sets of experiments scheduled for the two weeks period involved using the simple pendulum to determine the acceleration due to gravity and measuring the specific heat capacity of a metal using the mixture method. These two sets of practicals were performed over a period of two weeks.

School B

This school has a student population of about 1000 males. Only boys are admitted to forms I through V, and a few female students are admitted into form VI. Some female students prefer to study form VI science subjects in this school, rather than at School A, because of the mixed classes, the presence of university lecturers, and the good G.C.E. "A" level examination results in science in recent years. The curriculum consists of traditional academic subjects and some technical subjects, with much emphasis on science. About 25% of the students who take the G.C.E. "O" level examination do well in science subjects and hence go on to form VI and subsequently enter university. The administrative head is male, and so are most of the teachers. Because there is a shortage of physics and mathematics teachers, university lecturers help with these two subjects in form VI by working as part-time teachers. Three people teach physics in forms I to V and they also teach mathematics.

This school also has a separate building for its science laboratories. In the physics laboratory, adequate facilities were provided to teach physics and the other science subjects up to form VI when the laboratories were built in the 1960s. Facilities in the physics laboratory have deteriorated to the extent that there is little equipment in stock in the preparatory room. Basic equipment to do practicals and demonstrations is severely restricted, and the physics laboratory is almost bare. In the laboratory are two long wooden tables with gas taps and electrical plugs along the sides, two long concrete tables fitted with water taps along the walls, a teacher's demonstration table fitted with gas and water taps, a blackboard, and empty

cupboards. The laboratory is lit by windows along the sides, but there was not a single stool for teacher and students to sit on.

Physics classes are held in a classroom adjoining the building housing the laboratories. The classroom is spacious, well-ventilated, and bright on a sunny day. On a cloudy day the classroom is dark even if there is electricity because the electrical fittings on the ceiling and walls have been removed. Only electric cables, taped to provide insulation, remain in the places of the fittings. A blackboard and demonstration table are at the front of the classroom. The classroom also contains 10 wooden-topped concrete tables fixed to the concrete floor. Each table is designed for two students to write, but the tables could also be used for practical activities. There were few stools for the students to sit on; most students were leaning against the walls so they could copy from the blackboard. The few students with stools clustered around the demonstration table in order to hear what the teacher was saying. During demonstrations, students stood on the tables to see what the teacher was doing.

There were more than 40 students in form V science. Physics practicals for form V were conducted during a double period (80 minutes) in the morning. Students worked in groups of five because there was not enough equipment to set up more than one set of practicals. The teacher usually asked students to come with instruments so that there would be enough for every group. Two practicals were scheduled for a two-week period; one was performed by the students and the other was done as a demonstration by the teacher. The experiment to determine the refractive index of glass was performed by the students, while the teacher demonstrated how to measure minimum deviation of a triangular glass prism.

School C

School C is also a school for boys, with an enrolment of about 600 students. Female students are admitted to do sixth form courses in arts (English, French, geography and history) and economics. The curriculum consists of grammar school type subjects with emphasis on the art subjects. In recent years the G.C.E "O" level examination results in physics have been very good. This has caused an increase in the number of students doing physics in form V. The adminstrative head is male, and so are about 60% of the teachers. There is a shortage of physics and mathematics teachers, with only two physics teachers in the school.

The physics laboratory is not as spacious as the ones in schools A and B. It contains three wooden tables at the centre and two concrete side tables. The side cupboards house some instruments that have become obsolete, yet they are well kept. The preparatory room holds some additional equipment. There are not enough instruments to teach physics practicals in form V, but the equipment that is available is well cared for. There is no laboratory assistant, so the physics teacher sets up all the practicals and the students help him to clean up after practicals.

Physics classes are held twice a week after the regular school hours. These classes were held on Friday afternoons from 2:30 to 4:00 p.m. and on Saturday from 12:00 to 2:00 p.m. These hours are for the convenience of the physics teacher, who is pursuing another course. Form IV and form V physics classes are combined and taught as one class, and students from other schools also attend these classes. Of the 50 students in the class, 25 were in form V, 15 were in form IV, and 10 were students from other schools. Students worked in groups of four during practicals.

Teacher A

Teacher A is professionally trained and holds a Bachelor of Science degree in physics and mathematics from a British university. Her 10 years of experience teaching physics include three years at school A. Teacher A teaches physics in forms IV and V and mathematics in form V. She is an active member of the Sierra Leone Science Teachers Association. Teacher A was observed during two practical classes and contributed one recorded interview to this study.

Teacher B

Teacher B holds a Bachelor of Science degree in education (in physics and mathematics) from the University of Sierra Leone. He is relatively new to the profession, with three years of teaching experience. He teaches physics in forms IV and V and mathematics in form IV. Teacher B conducted two revision and demonstration lessons which were recorded verbatim. He supervised a practical and conducted a demonstration that would have been done as a practical if the required equipment had been available. Teacher B also took part in an interview which was recorded.

Teacher C

Teacher C holds a Bachelor of Science degree in physics and chemistry and a Diploma in Education from the University of Sierra Leone. He has been teaching physics for seven years at School C. He teaches physics in forms IV and V but teaches both classes as one class. Teacher C supervised two practicals and took part in one interview for this study.

CHAPTER 3

LITERATURE REVIEW AND RESEARCH METHODS

Review of Literature on Laboratory Practical Activities

Even though the laboratory has been regarded as having a major role to play in helping students understand science, the results have remained disappointing. At one level, covering the curriculum consistently takes priority over first-hand practical experiences when teachers make inevitable choices about the use of limited time. At a second level, there is confusion about the role that practical work can and should play in helping students to understand scientific concepts. This literature review examines recent research on the place of laboratory practical work in the teaching of science, with special attention to the teaching of physics.

Researchers in the area of science education have proposed various explanations for why students have difficulties with science in general. Some of these theories correspond with students' own ideas about why they have difficulty with physics practicals. When Brook and Driver (1984) investigated 308 secondary students' understanding of energy, they asked students to use pre-existing ideas to explain selected phenomena in energy. The results indicated that students' pre-existing ideas do not always explain phenomena in science adequately, and sometimes lead students to make wrong associations. In another study, Brook, Briggs, Bell, and Driver (1984) investigated students of varying abilities and science backgrounds on their understanding of heat (conduction). The students based their explanations of conduction of heat on accepted ideas rather than on a scientific

explanation. They did not have consistent frameworks to draw on to explain events. This study suggested that when students are presented with ideas in science lessons, they tend to make them fit into their intuitive ideas. These studies signal the importance of attention by teachers to their students' existing ideas about a concept, particularly in the laboratory practical context in which students interact directly with phenomena with only occasional contact and interaction with the teacher.

Among the barriers identified by Colton (1982, p. 38) as influencing students' understanding of science and mathematics is the students' literal interpretation of schematic diagrams.

> Most science and math teachers rely heavily on diagrams to explain their work, but these are often not understood and are frequently misleading; they probably fall into the category of barriers which we have labelled as pedagogenic-those which are the result of teaching, not necessarily of poor teaching, but teaching that is unaware, lacking in a conscious effort to understand and forestall the difficulties of the learner.

Flexer (1982) investigated barriers that influence students' difficulties in understanding science. In reference to the circuit and ray diagrams in electricity and optics, Flexer holds that there are some concepts, objects, instruments and phenomena in science that can be represented diagrammatically. These representations are meant to help students visualise the concepts or positions of the instruments. Students reconstruct their knowledge to fit more closely with the representation than with what is being represented, and thus such representations may be unintentionally misleading. When students have such difficulty, they have a problem of confusing reality with representation.

Often, science instructions present views of phenomena that conflict with concepts students already have about science. Driver and Easley (1978) and Driver and Erickson (1983) have reviewed studies in this area. Some science educators (Champagne et al., 1985a; Driver, 1983; Driver & Oldham, 1986; Hawkins, 1983; Hewson & Hewson, 1983; Hewson & Hewson, 1984; Nussbaum & Novick, 1982) argue that science instructions should be presented so that students' preconceptions could be identified and improved. Students' preconceptions in science are sometimes valid, and they use them to operate in their daily environment. It is plausible that students may fail to acquire practical skills from laboratory activities and fail to relate activities to theories when their practical experiences conflict with conceptions already held.

Whether one views science teaching as replacing prior (incorrect) concepts or as building on students' preconceptions about scientific phenomena, it is commonly assumed that practical activities play an important role in science teaching. Barnes (1976) argues that students are faced with a dichotomy between school knowledge, the information presented by the school which is largely learned by rote, and action knowledge, which forms the basis of students' understanding of everyday phenomena. White (1979) underscores the need for laboratory practicals in the teaching of science, arguing that practicals link science with daily life and provide experiences upon which to frame new concepts. Champagne et al. (1985b) support practicals because of the extent to which such experiences can relate aspects of the problem to relevant prior experience (p. 85). Hawkins (1974) also supports students' activities in the laboratory but cautions that such activities should be structured in order to make scientific concepts explicit to the students. Taking a

more critical perspective, Driver (1983) suggests that it is important to regard the role of practical activities as an assumption. "We have placed faith in discovery: that by doing experiments pupils will better understand ideas. This may have a part to play, but experience alone is not enough." She goes on to say:

> It is common to see science lessons which end with the clearing up after the practical work is finished. The time for the important discussion of how the experiences gained relate to the new ideas is missed. Activity by itself is not enough. It is the sense that is made of it that matters. Teaching strategies are needed which help pupils think and talk about the significance of their experiences and, most important, time for teachers to talk through pupils' experiences with them. (p. 49)

The data presented in this study testify to the insightful nature of this commentary.

Even though there is widespread agreement (at the level of espoused theory) that practical activities in the laboratory should improve students' understanding of scientific concepts, there is little evidence (at the level of action) that science teachers organize practical work in ways that enable students to acquire the desired understanding from laboratory practicals. Few studies have addressed the need to develop, and to integrate into the existing context of teaching, strategies that will enhance students' understanding of scientific concepts through laboratory practicals.

Raghubir (1979) speaks of the need to develop a teaching methodology that will improve students' understanding in laboratory practicals. He expresses the opinion that teachers do not give students the opportunity to do practicals that will

explain concepts but instead get students to do practicals that verify facts already known. One result is that students fail to make effective use of laboratory work.

> Teachers tell students too much; they deprive them of the opportunity to learn for themselves. In the laboratory, for example, they are likely to tell them just about everything—how to assemble an apparatus, how to design an experiment, and what outcome to expect. Of course, they think they do this for a good reason—to save time and to "save the experiment." However, it seems that in spite of their enthusiasm, planning, and zeal, the students frequently leave the laboratory having performed the exercise well, but with low retention of information and even lower comprehension of the significance of the information. (p. 13)

Even earlier, Thomas (1972) and Rasmussen (1970) saw the need to develop teaching methodology that could be used in teaching practicals. Thomas supports the use of laboratory practicals but maintains that the question of how best the laboratory can be used as part of an instructional programme remains to be answered. In giving his conditional support to the use of the laboratory to study science (biology), Rasmussen suggests that "if the biology laboratory is to be used to advance understanding of how science operates, the instructor will have to identify that behavior he is trying to promote and design objectives and activities that will achieve these ends" (p. 293).

Millar (1989) advocates that science should be taught as process-based activities in schools. The activities he classifies as process-based are observing, classifying, interpreting, predicting, evaluating, inferring and hypothesizing. He believes that the essence of science in any school's curriculum is to develop these

processes in their students. He suggests that these process objectives should be set alongside those relating to content and concepts as though they are each part of one entity. Millar holds that teachers should focus on the development of these processes while teaching science. He claims that "by making these processes the focus of instruction (either explicitly or implicitly), pupils will develop very general skills which they can apply to new problems in new areas, either within science or beyond" (p. 51).

Woolnough (1989) also proposes a holistic method of teaching science in schools as against the practice of reducing science teaching to component parts. Physics teaching in Sierra Leone can be viewed as compartmentalized into theory for content and concepts and practical work for the verification of known facts. Woolnough anticipates the extent to which the method of assessing students in physics in Sierra Leone influences the teaching method teachers adopt. "What is less often recognized is that the form of the assessment procedures can, by defining what is regarded as important, fundamentally affect the way that a subject is taught" (p. 123).

Renner (1982) contrasts two theories of learning, theories that he distinguishes as "A" and "B." Theory A explains how students learn information received from teachers. The teaching procedures used in Theory A involve the teacher informing students, students verifying what they have received from their teachers by performing experiments with known outcomes, and students practicing what they have acquired by attempting questions and problems from their textbook. In Theory B, students are exposed to experiences that are to be acquired and from which they will create what is to be learned. The procedures involved in Theory B are exposing

students to experiences, introducing the language (terms) to describe the observed phenomena, and organizing the new idea with existing knowledge to expand that knowledge and the newly acquired knowledge. Efforts by Schneider and Renner (1980) to compare instruction organized in terms of these two approaches to learning showed positive results for Theory B, but there is no evidence that their work has spread beyond the schools in which it was developed. It is important to note that there is a strong similarity between Renner's Theory B approach to learning and Driver's recommendations for the importance of making sense of laboratory activities.

Some of the studies in this review point out that there exist factors that inhibit students' understanding, explanation and application of scientific facts and concepts. A few studies also point out that through laboratory practicals these inhibiting factors could be reduced, if not eliminated, and hence improve students' understanding of scientific facts and concepts. The studies reviewed make a strong case for the use of laboratory practicals to improve students' understanding, but that case rests heavily on specific teaching strategies that are not commonly used.

As some educators caution, the methods used to teach practicals may not accomplish the desired effects. It has been observed that teachers tend not to discuss students' results and observations after practicals, that teachers often tell students what to do and look for during practicals, and that students participate in limited ways in the process of investigation. Alternative strategies for conducting laboratory work have been proposed, but it is also noted that the method of assessing students can influence the methods teachers use in the practical context.

Overall, the studies reviewed indicate the importance in every school context—national, provincial, and local—of inviting science teachers to examine the role of laboratory work in their teaching of a particular science subject such as physics. It is clear that the goals for laboratory practical work are very important ones, just as it is clear that these goals are not automatically achieved by having students manipulate equipment in a science laboratory.

Research Methods

The section explains how entrance was gained into the schools and how the researcher contacted the teachers. Also included in the section are descriptions of the data collection design, the study's participants and the plans for data analysis.

Contacting Principals and Teachers

Obtaining permission from the principals and establishing a conducive working relationship between the physics teachers and the researcher was crucial to the successful collection of data for this study. Two separate informal meetings were held with the physics teachers of each school during lunch breaks. This was to ensure that these teachers would be free from teaching and that no distraction be caused by the presence of the researcher in the schools during teaching sessions. During the first meetings, the researcher discussed with each teacher what the study was about and what it involved. Apart from the discussion, each teacher received a copy of the study's proposal to read through before the second meetings. The purpose of the first meetings was to provide the teachers with a basic understanding of the study; the second meetings would provide opportunities to ask questions after

reading the proposal, before they gave their consent to participate. School-based research that involves observing and interviewing teachers and students is not common in Sierra Leone. The researcher's apprehension after the first meeting with each teacher was that they might feel that the study was intended to investigate their teaching methods.

Thus it was not surprising that two of the three teachers found it difficult to believe that the research was not intended to question their methods in the laboratory. The researcher explained to them that the study would not only investigate their methods but would also report on how students do physics practicals. In response to the teachers' concerns, it was agreed that only their practicals would be observed. The third teacher agreed to let the researcher sit in on his physics classes in addition to observing his practicals. The three teachers agreed to participate in the research and each signed a consent form.

Three separate informal meetings were held with the principals of the schools. The researcher used the informal method of meeting the principals because, as Goetz and Lecompte (1984) believe, "Generally, informal, face-to-face contacts are more effective. People are more likely to respond positively to direct, interpersonal appeal, and informal networks are often trusted more than official channels" (p. 88). Also, the researcher had helped in teaching physics in form VI in two of the schools and had also loaned apparatus for physics practicals to the third school. The principals gave their permission to work in their schools and later introduced the researcher to the physics teachers who had already given their consent to participate in the study. The strategy of first making contact with participating teachers, then the principals, and finally back to the participating teachers was

intended to build trust and friendship between the researcher and the participating teachers. It was also intended to reduce the feeling that the teachers were participating because of directives from the principals.

Design of the Data Collection

Data were collected in three secondary schools in Freetown over a period of eight weeks. The first two weeks were used in making contacts with the principals and participating teacher in each school. The remaining six weeks were used to collect data, two weeks in each school. In each school the teacher identified two students who were interviewed after physics practicals. While observing a class perform practicals, attention was focussed on one of the identified students either when working alone or in group. The two students were observed during two separate practicals.

The individual focus strategy was used in order to observe the specific nature of behaviour exhibited by students, including manipulation of apparatus, asking questions of particular interest, and the extent to which all students in a group shared tasks or permitted one or a few to direct the group's activities (Shymansky & Penick, 1979, p. 198). As students were performing practicals, the researcher observed how teachers asked questions, gave directions, transmitted information, provided feedback and observed students at work (Shymansky & Penick, 1979, p. 179).

After the practicals two students were interviewed separately in each school. The students that the researcher focussed his observations on were the ones that were interviewed after practical classes. These interviews were to corroborate the researcher's observations during the practicals and to record students' impressions

about the practicals they do in schools. The interviews further tried to determine the extent to which students understood what they were doing and to talk about the difficulties encountered and how they approached them. Below are some of the questions the researcher asked the students.

1. What was the practical about?
2. What were you required to investigate in this practical?
3. Which aspect(s) of this practical do you have a problem with?
4. How did you overcome the problems?
5. How did you get your numerical values?
6. Could you think of possible areas that will produce mistakes in getting your values?
7. How are you going to analyse the values that you have recorded?
8. Will you have problems in analysing your values?
9. Why do you have to do physics practicals?
10. How would you summarize what you have learned from this practical?

After observing students doing practicals and interviewing them after the practicals, the participating teachers were then interviewed. The interviews provided information about the teachers (qualifications, teaching experience, teaching schedule), about how students are selected to study physics in form V, about why teachers taught physics practicals the way they do, about how public examinations influence their teaching methods, and about their general views on physics teaching in Sierra Leone. Questions put directly to the teachers individually included the following:

1. How are students selected to study physics?
2. Why do students do physics practicals?
3. How often do students do practicals?
4. Which aspects of physics practicals do students have difficulty with?
5. How do you conduct physics practicals, and what is your rationale for using such method?
6. If there were no public examination, would you conduct physics practicals differently?
7. How do students relate theory to practice in physics, and what part do practicals play in this process?
8. What type of practicals do students perform?
9. How would you describe the G.C.E. "O" level physics practical examination?
10. If you were asked to prepare the G.C.E. "O" level physics examination, what types of questions would you set?

Participants in the Study

Participants for this study were three physics teachers (a female and two male) and 116 students aged 16 to 18 years from three different secondary schools in Freetown. The total of 116 students included 20 girls from school A, 46 boys from school B and 50 from school C. These students are in form V science and are being prepared for the G.C.E. "O" level physics practical examination in June 1990.

Preparation of Data for Analysis

Extensive field notes were taken in order to describe the laboratories and students' and teachers' activities while working in the laboratories (Tamir, 1977; Goetz, 1976a, 1976b; Olson & Russell, 1984). Interviews with teachers and students, revision lessons and demonstrations prior to practicals were recorded verbatim using a tape recorder. Most recordings were transcribed; the complete interviews for School B are presented in Appendix A. The interviews recorded included two from school A (one from each student), four from school B (two each from two students), and three from the teachers (one from each teacher). The interviews of students from school C were not transcribed and reported because they contained little more than one or two word responses that did not add anything new or different from what the students of the other schools said. The two revision lessons and demonstrations recorded verbatim were those of the teacher in school B (See Appendix A).

Analysis of Data

To fully familiarize myself with the data, I listened three times to each of the recordings of interviews and observed lessons and demonstration for each school. The data were then transcribed by hand and typed into separate files on a computer. The anonymity of the participating schools, teachers and students were preserved by using codes for each speaker. The printed transcripts were then read a number of times to identify major themes and supporting illustrations. Identified categories in the data were highlighted using different coloured makers for each category throughout the printed matter. The data for each school were categorized into

laboratory facilities and apparatus; instructional method; teachers' and students' activities before, during, and after practical work; students' narrations about difficulties encountered during practical work; students' views about the type of practical work they do at school; students' views about the methods teachers employed to teach physics practicals; and teachers' views concerning physics practicals in relation to understanding physics concepts and how the G.C.E. "O" level physics practical examination influences their teaching methods. Subsidary files for the above categories were created, and portions belonging to a particular category for each school were transferred to those files.

The above categories were later reduced to four categories that could tell the story of the study in a logical sequence.

1. Teachers' Goals for Practical Work
2. How Teachers Conduct Practical Work
3. Pressures and Constraints on Practical Work
4. Consequences for Students

Sorting data into these categories permits comparisons of themes and identification of patterns to be related to the conceptual framework drawn from the literature reviewed. Renner's (1982) study is particularly helpful in describing consequences of the major teaching patterns identified.

CHAPTER 4

PHYSICS PRACTICAL WORK IN THREE SCHOOLS IN SIERRA LEONE

This chapter reports excerpts from data collected at each of the three schools in Freetown in October and November, 1989. The purpose of this presentation of data is to indicate in some detail the nature of laboratory practical work performed in each school, along with the perspectives of the teachers and a few of the students. The data include lessons before practical work, teachers' and students' activities during practicals, and interviews with students and teachers after practicals. In the presentation of data, the letters A, B, and C designate, respectively, the teachers at schools A, B, and C. The letters JK indicate the statements by the investigator, and various student comments are designated by S.

Physics Teaching at School A

In school A two sets of practicals were set up for 20 female students; these enabled each student to work independently. The two activities were determination of acceleration due to gravity (using the simple pendulum) and measurement of the specific heat capacity of a metal. The practical on measurement of specific heat capacity was a new set added to the existing set involving the simple pendulum. Teacher A spent the first 10 minutes explaining procedures and precautions to be observed in performing practicals on measurement of the specific heat capacity of a metal. Below is an excerpt from the explanation before the practical. The teacher's statements strongly suggest a *verification* perspective on the role of practical work; theory has already been learned and understood, and the personal

activities will verify that learning, with appropriate consideration for experimental error.

Excerpt from a Lesson introducing Practical Work

A: The outer containers are aluminum but there are calorimeters in them. Some are copper ones with copper calorimeters in them. A calorimeter is just a metal cup. Some of you have copper and the others have aluminum calorimeters. In between the calorimeter and the outer container, the space is filled with some poor conductor material. This space is supposed to be well stocked with poor conductor. Some of you have cotton wool, others have shredded paper, and we filled it up with toilet tissues so that little or no heat is lost through the calorimeter to the outer container. Then you have the stirrer with which you stir the liquid after you put the metal in the calorimeter. Provision is also made for the thermometer.

So according to the theory we have covered, we are going to use the fact that the heat lost by the metal to water in the calorimeter is equal to the heat gain by the water. We are going to heat the metal in the pot containing water. The temperature of boiling water we measure with a thermometer. So we will assume that the temperature of the metal is the same as the temperature of the hot water. As I have told you before, the transferring of the metal from the hot water to the calorimeter is where you have errors coming in. This has to be done very quickly. Also you do not have to drop the metal into the calorimeter because water will splash out from the calorimeter, thereby reducing the mass of the water

that has been recorded. So it has to be put gently into the calorimeter. Heat will be lost to the atmosphere when transferring the solid from the hot water into the calorimeter. You have to keep stirring after putting the solid into the calorimeter until a steady temperature is reached which is the final temperature. With what I have told you, you should be able to carry out the experiment.

There were no laboratory manuals or hand-outs for practicals from which students could follow instructions. The students used their text books to do practicals. During practicals Teacher A went round observing students at work and explaining points that may not have been made explicit during regular physics classes. The assistance to students ranged from how to set up practicals to the use of measuring instruments. The laboratory assistant also helped students set up the materials and instruments. No interaction between students was observed.

After the practical work, Teacher A identified two students whom the researcher interviewed separately in order to explore the extent to which they understood what they were doing and to talk about their difficulties. Included here is an interview with the student who worked on the measurement of specific heat of metal. The student is generally clear and straightforward, and is definitely aware of the relationship of practical activity to the examination at the end of form V. The student reports limited and delayed communication with her teacher, and specifically describes the purpose of the work as a check on whether or not the theory learned earlier has been understood. Reported weaknesses involve manipulation of equipment and subsequent analysis of data.

Interview with a Student after Practical Work

JK: What was the practical about?

S: It was to determine the specific latent heat by using the calorimeter.

JK: Did you understand what you were doing?

S: Yes, I understood the procedure.

JK: Did you read about the practical before coming to the laboratory?

S: Our teacher gave us the notes about the procedure and precautions before coming to the laboratory.

JK: You did not read about the practical yourself?

S: No, the teacher gave us the notes first before we had the practical.

JK: Which aspects of the practical did you have problems with?

S: I did not know how to measure the temperature at first.

JK: What do you mean by *I did not know how to measure the temperature*?

S: That was my first time I measured the temperature of a liquid, so I did not know how to go about it.

JK: How did you overcome that problem?

S: The teacher explained to me how to do it.

JK: How did you read off the values from the thermometer?

S: The thin line in the thermometer, when you see it go up when stirring the calorimeter and stop at a point for a while, that gives you the value for the temperature.

JK: What do you call the *thin line in the thermometer* that moves?

S: [No response]

JK: What do you call the liquid in the thermometer?

S: [No response]

JK: It is called mercury. Could you think of areas that will produce error in your practical?

S: Yes. If you take the solid out of the hot water you should do it carefully so that when you put it into the calorimeter it does not splash water or else you will not get an accurate reading and then you should take the solid from the hot water as fast as possible so that it will not lose heat to the atmosphere.

JK: How do you hope to analyse your readings?

S: After you have got the mass of the solid, mass of the calorimeter, mass of calorimeter and water, the initial temperature of the water in the calorimeter and the temperature of the mixture in the calorimeter, you subtract T1 from T2 so that you will get the temperature of the calorimeter.

JK: What are T1 and T2?

S: T1 is the initial temperature of the water in the calorimeter. T2 is the final temperature of the water in the calorimeter.

JK: What were you investigating during the practical?

S: [No response]

JK: Were you investigating that the heat given out by a hot body is equal to heat gained by another body?

S: Yes.

JK: Which body gave out heat and which one is receiving heat?

S: The hot water is giving heat to the solid.

JK: What about the solid and the calorimeter?

S: The solid is giving out heat to the water and calorimeter.

JK: So how will you analyse your readings?

S: [No response]

JK: Why do you have to do physics practicals?

S: We do practicals to know if we understand the theory that we have been reading. We also do practicals to prepare for the G.C.E. "O" level physics practical examination. Most of the marks in the examination are gained from the practical. If you fail the practical, you will fail the whole examination no matter how well you answer the theory and the objective questions.

JK: Do you think that the practicals you have been doing will prepare you adequately for the examination?

S: Well yes, although I don't understand some of the practicals very well but some I do understand.

JK: What problems do you generally have with practicals?

S: I have problems with understanding instructions, following procedure, setting up of apparatus and finding gradients from graphs.

JK: Which aspect are you having difficulty with?

S: I don't understand how to go about it to find the gradient.

JK: Have you discussed it with your teacher?

S: No, we have not yet discussed it.

JK: Why have you not discussed it?

S: Because we have not yet submitted our practical exercise books for marking.

JK: How many practicals have you done so far?

S: We have done five practicals but the teacher has not marked them yet.

JK: What would you say the teaching is like?

S: The teacher sometimes gives us notes about the practicals we should do. Some other times she asked us to read about them and find out how to do them.

JK: Do you have a practical manual?

S: What is that?

JK: It is the book that you use to do practicals, it has instructions and procedures of how to do an experiment.

S: No.

JK: Where do you get instructions to do practicals?

S: Some of the practicals are in our physics texts but we do not have a particular text for practicals. We use our text to read for practicals.

JK: But your text does not give instructions for practicals?

S: The text gives instructions but they are not too clear to understand.

JK: Do you understand when your teacher teaches and conducts practicals?

S: We do not understand how to go about with some of the practicals. She does not explain to us: she says that we should read on our own and to do the practicals which are difficult to follow without assistance.

JK: How often do you do practicals?

S: Once a week.

JK: When did you start doing practicals?

S: When I came to form V. In form IV we did theory only. If we had done practicals in form IV. it would have helped us to understand the theory better and to be able to do well on the practical [exam].

JK: Do you know why your teacher did not do practicals in form IV?

S: She used to tell us that we have a lot of theory to cover for the G.C.E. "O" level examination. I think it is the pattern to do practicals in form V.

JK: After your practicals. do you discuss your readings with the teacher?

S: No. since we started practicals she has not yet looked at them. We don't know whether the answers are correct or not. She does not look at them.

The school day was over by the time the interviews with students were finished. An appointment for an interview with Teacher A was fixed for two days after the practical work. This interview was conducted to explore the teacher's views about physics practicals and the teaching methods used to conduct practicals in physics. Problems prevalent in the teaching of physics in general in Sierra Leone were also discussed during the interview. Below is an excerpt from the interview with Teacher A. When asked how she would conduct practicals if there were no examination. Teacher A indicates that practical work should follow immediately after presentation of theory; she also indicates that laboratory activities are helpful to learning theory.

This excerpt includes a passage in which Teacher A very clearly describes learning as something that happens after teaching, when the student is at home with books and notes. She assumes that notes given to students will convey adequately the concepts they describe if the student devotes proper time to studying the notes. Teacher A also discusses the negative attitude that students have toward physics, which they tend to see as difficult and impractical.

Excerpts from an Interview with Teacher A

JK: How are students selected to study physics?

A: Usually after their third form they are streamed, invariably according to their performance in the different subjects. Those who are mathematically good and seem to have the aptitude for the sciences go into the science stream where it is automatic they have to do physics. The others are streamed into the arts, economics, and commercial. So it is automatic they do physics in form IV if they have been streamed into the science stream.

JK: Why do students do physics practicals?

A: To aid the theory, to give a better understanding of the theoretical aspect of the subject.

JK: How often do students do practicals?

A: In the fifth form it is once a week. We try at least once a week. In form IV usually they don't have practical for the first one or two terms, but when they start doing heat and other topics which have practicals that can be done in the school they start the practicals. So towards the

end of the fourth year and then also at the fifth form until the G.C.E. physics practical examination.

JK: What difficulties would you say students have when doing practicals?

A: There are certain areas where they find the theory difficult and consequently the practicals. I find that with experiments on moments. The students may be able to perform the procedure, go through the procedure, but then the essence of the experiment is not well understood. For electrical experiments, we used to have problems because of availability of apparatus but now that we have ours it is not as bad as before. But connecting circuits take a long time to do. And again putting the theory to the practicals in electricity. But otherwise I don't think we have any particular areas that give the students so much problems.

JK: How do you conduct physics practicals and what is your rationale for adopting such a method?

A: Since the students are not usually too many in the science stream, I have each student working on her own so they do it individually. And because of lack of apparatus they do it on a rotational basis so that I have to set a series of practicals. Usually, I set four practicals at a time and each student should do the set of four before going to the next. So we just rotate the apparatus around until the first set is covered. I tried to keep the experiments on mechanics together, the experiments on heat together, etc. We have a shortage of stop clocks and a shortage

of thermometers, and the experiments that can be set are limited by the apparatus available. I cannot set more than four simple pendulum experiments, so if I want each student to work on a practical herself I have to set more than one set of experiment.

JK: In the last physics practical, I observed that students do not have physics practical manuals?

A: Before the practicals I send them the particular experiment that we will be performing. They are suppose to read the section pertaining to the experiment in their textbook and write out their procedures and whatever is relevant to the experiment before coming to the lab. Whatever I want them to do after performing the practicals in their write-ups, I give to them. So they have all that before coming to the lab. The problem I am having is that a lot of them neglect the work that is given before the practicals, so much so that they are lost when they come to do the work. But technically they have all that is required for the practicals before hand.

JK: Don't you think that if you monitor the students' work by asking them questions pertaining to the practical to be performed, it will make them read the relevant portions for the work?

A: Well, it is a question of time. We are starting in the fifth form. The students have the G.C.E. "O" level physics practical examination to take in May. So I am torn between throwing them out of the class if they are not prepared for the lesson and the amount of practicals we have to cover within that short space of time. Even though once in a while I throw

them out to keep them in line, it is difficult. Otherwise you will find that there are some students who will not do any of the practicals and they end up with a problem when the exams come.

JK: If there were no public examination how would you conduct physics practicals?

A: We are limited in apparatus but I would like to conduct practicals for each section pertaining to the theory, so that after I teach a particular topic we are able to go to the lab to do the experiments which are connected to that particular bit of theory. If one had a free hand time wise as well,we should be able to do it. But we are only starting the "O" level syllabus effectively in form IV. That means that we have about a year and a few months and that is not enough. We have to select those experiments we feel will likely come in the exams, concentrate on those, and just do one or two that are supposed to assist the theory the students learn.

JK: How do students relate theory to practice and what role do practicals play in this process?

A: I try my very best to get them to be able to relate theory to practice. This is why I want them to read beforehand, but there is a dislike for the subject. Therefore I think they spend very little time on the subject. The students are never prepared for the practicals; therefore they don't appreciate what you want to get at. If we do moments, for example, and give them three or four readings to find the unknown mass of an object, they cannot relate the calculations in the theory to the ones they have to

do after they have done the experiment. The reality of actually being able to perform the act in the lab does not really get to them; otherwise I won't have problems getting them to write up their labs.

JK: During the practical class, I observed that a student who seemed to know what she was doing could not tell the difference between the time taken to do a number of oscillations and periodic time.

A: Well she had difficulty because she had not read, she had not studied, she had not gone back to her books, because these are things that we have discussed at length and I don't think there is any more that I can give in that respect. If I teach a topic in class and students don't go home to read their text books, read their notes, there is nothing I can do. It means that they are never going to learn. The next time we move to another topic they forget what I have taught them. The teaching is one thing but the learning is another. If they are not prepared to spend the time with their work, then it is one of the problems that I am having.

JK: Do you usually conduct a post-lab discussion with your students?

A: Yes, we go through them in class, invariably after I have seen their practical work. Also I encourage them to come one at a time to me in the staff room with their problems so that I can assist them individually. As I said earlier, the class this year is big, about 25 students so it is not as easy as before. In the past years I discussed each practical individually with each student, but now it is only those who are willing to discuss their work with me that I will give time to.

JK: How would you describe the G.C.E. "O" level physics practical examination?

A: Well, with the limitations [of time and apparatus] the Exams Council cannot do much. A lot of schools really have problems with their apparatus, even finding those which are asked for in the examination. Teachers have to run around to the university and other schools trying to borrow apparatus. So I don't know what W.A.E.C. is going to do about it. The unavailability of the apparatus has limited the effectiveness of the physics practical examination. Right now I know there are a lot of schools where there are no practical lessons before the exams. Towards the exams they get the students to do one or two practicals they feel might come in the exams and that is it.

JK: How do teachers select the few practicals they think will be asked in the exams?

A: Over a period of a number of years we tend to see what the trend is. So teachers can predict what the practical examination will be like.

JK: If you were asked to prepare the G.C.E. "O" level physics examination, what type of questions will you set?

A: The paper now consists of a lot of objective questions, which is good because it tests the basic facts the students know. But they are not testing enough of the application of the subject. You study physics, then of what use is it? In the present syllabus, the exams do not actually examine the applications of physics as a subject. We are just teaching the students a lot of theory but they don't know what to do with the theory.

So perhaps if I have my way I will include a few more questions on the practical application of the subject so that students appreciate the subject as something practical. Right now it is one of the most disliked subjects in schools.

JK: What is the general attitude of students to physics?

A: Very negative. Very negative.

JK: Why?

A: I think there is a misconception that it is one of the most difficult subjects. A conception, I think, not a misconception, that it is one of the most difficult subjects, so they have a negative attitude even before they start learning the subject. In the initial stages of studying physics, it is a bit dry. I have to admit myself that it is dry. When you start topics like units, mechanics, etc., I think that tends to put them off. And yet it is essential that those topics be taught, because if you don't know how to measure you will not be able to do anything in the subject.

JK: Do you see a change of attitude towards the subject in the future?

A: Nobody is doing anything about it so I don't think there will be any change in the near future. At the university the attitude towards the subject is negative. There is no effort been made by the [physics] department to encourage anybody to go into the department. From that level it filters down. We are not going to have graduates in physics. We are not going to have good teachers in physics, teachers that have actually studied the subject, so that in the long run it has to filter down into the schools. We are going to make do with people who have

qualified in engineering, who are teaching physics as a "stop gap." The interest in the subject will be minimal; for them it is just a job, and they have no interest in the subject. If they start from that point at the university to make the subject more applicable to the students, I think it might filter down to the schools. We will then get people in the department who have interest in the subject, who will teach in the schools, and thereby pass the interest on to the students. But right now nothing is being done to improve on the situation and the schools can't do much.

JK: I also observed that students did not have practical manuals and some even do not have a textbook. Does this cause problems in teaching the subject?

A: The students are given the "O" level syllabus in form IV, so a lot of them have their textbook for the "O" level in form III, where they actually start the subject. Students study general science in forms I and II. There is a text book prescribed; most times teachers give notes. With the notes and working in the library, students should be able to get as much information as necessary for the course. I haven't experienced that as a problem.

JK: Could you think of suggestions for improving on the methods of engineering graduates who teach physics?

A: I think that workshops and seminars could be organized to update these teachers and other physics teachers on recent methods of teaching physics. This will help because the problem lies in the

approach to teaching the subject. If these teachers are given some direction as to how to approach the subject to students starting physics for the first time, how to make it interesting and do demonstrations, perhaps it might go a long way to help. We have a well-stocked lab in this school, at least up to the sixth form level, with the exception of a few items that are short. I found out that other teachers in the lower forms do not make use of the lab. I am not saying that students in the lower forms should do practicals, but I think that even if once a month teachers take them to the lab and do a class demonstration on what has been taught, show the students the instruments that are available, let them see what some of these things look like, that might help the students not feel that the subject is abstract. Some of the relation to practical can be pointed out in everyday life. From such workshops and seminars, some upgrading of the teachers' knowledge coupled with methodology in the subject will be necessary. A programme could be developed where the teachers themselves will appreciate that physics is a practical subject so that they might be able to pass it on to the children.

JK: Will the present economic situation in the country encourage teachers to prepare adequately to teach?

A: Of course, no. There is going to be a problem in schools, with education in general. Yes, more in subjects where people have the conception that it is difficult. Nobody is going to make an effort, spend time and spend energy with a subject that they probably think is difficult, and yet they are not paid for it. There is no adequate reward for the

amount of effort that it takes to make the subject interesting. Especially if it is someone who is not interested in the subject, it will be difficult. Take somebody from the engineering field. He imagines that in his field if he has a job he will earn about 10 times what he is presently earning as a teacher. He is going to do about one-fifth of the amount of work he feels the salary deserves. It is going to be difficult.

The interview with Teacher A concludes the data reported from School A. We turn now to a similar account of practical work at School B.

Physics Teaching at School B

The facilities in school B have deteriorated considerably. Very little basic equipment (rectangular glass blocks, triangular glass prisms, etc.) is available. Students worked in groups of five in practical classes; there were seven rectangular glass blocks for a class of 46 students, and two students each brought a glass block to make a total of nine. Two sets of practicals were scheduled for a period of two weeks; the students performed one while teacher B did a demonstration of the other. The students could not do the second practical because there was only one triangular glass prism available. Teacher B conducted demonstrations of the scheduled practicals during physics classes one day prior to the practicals. These demonstrations and revision classes were teacher-directed; he did the talking, explaining and writing of theory for practicals on the blackboard. During these demonstrations teacher B gave step-by-step explanations of how to conduct practicals. He also told students how to record and analyse their results. During practical classes teacher B wrote the instructions and drew diagrams and tables for

the tabulation of results on the blackboard. Teacher B described observations students should make, gave direct answers to students' questions about the experiment, and performed parts of the experiment for students in response to questions about procedure. Teacher B went round directing and assisting students with their work as and when the need arose.

Two sets of revision lessons and demonstrations were observed and recorded. The first lesson and demonstration was on measurement of the refractive index of glass; the second involved measurement of minimum deviation in a triangular glass prism. Below is an excerpt from the lesson and demonstration on the refractive index of glass.

Lesson and Demonstration before a Practical Class

B: We are going to look at the laws of refraction of light and how to measure the refractive index of light for a given medium. [The teacher draws a standard diagram for light passing through a glass block, bending toward the normal on entering and away from the normal on leaving.]

Let mm' represent the boundary between the media—air and glass.

NO represents the normal to the plane.

AO - the incident ray

OB - the refracted ray

i - the angle of incidence

r - the angle of refraction

The angle between the normal and the incident ray is called the angle of incidence. The angle between the normal and the refracted ray is called the angle of refraction. The laws are

1. The incident ray, the refracted ray and the normal all lie on the same plane.
2. The ratio of the sin i to sin r is a constant.

This constant is called the refractive index from one medium to another; it is usually designated by n. Now let us look at refraction from another point of view. Who can define refraction in terms of the velocity of light from one medium with respect to another medium?

S: (Inaudible).

B: Anybody else? Yes.

S: The velocity of light from less dense medium is greater than the velocity of light in the other medium.

B: Given two media, the ratio of the speed of light in medium one to the speed of light in medium two is a constant. It can also be defined as

$$\frac{\text{THE VELOCITY OF LIGHT IN MEDIUM ONE}}{\text{THE VELOCITY OF LIGHT IN MEDIUM TWO}} = \text{CONSTANT.}$$

At the end of this class you should know how to find the refractive index of a glass block. I will also explain to you how to find the refractive index using the idea of real and apparent depth.

What happens when an object is immersed in water ?

S: It increases in size.

B: Is that true ?

S: No.

B: What actually happens ?

S: It appears to be nearer.

B: It appears to be raised. So therefore you have an apparent depth and a real depth. What is an apparent depth ?

S: (Inaudible).

B: The apparent depth of an object is the depth of the object as it appears raised. [Teacher B sketches on the blackboard to explain the difference between real and apparent depth.] What is the real depth ?

S: The actual depth of the object.

B: We all know how to read the meniscus of liquids. What is the shape of the meniscus of water ?

S: Concave.

B: The real depth is the distance from the object to the lower part of the meniscus. The apparent depth is distance of the image of the object as it appears raised inside the liquid (in this case, inside the beaker). So we can also define refractive index as the ratio of the [real] depth to the apparent depth. Having arrived at these definitions of refractive index, the most important point I want you to note is how to find the refractive index of glass. What we have to do in the lab is how to find the refractive index of glass. In this case what will be the first medium?

S: Air.

B: What will be the second medium?

S: Glass.

B: I will demonstrate it to you. In any experiment you do, it is important that you read the instructions first. A lot of students fail the G.C.E. "O" level practical examination because they do not know what to do. They are not patient enough to read the instructions well. You put a piece of drawing paper on the drawing board. The first step is to draw the outline of the rectangular glass block. The whole idea is for us to be able to define an incident ray and then find the angle of incidence, from which we find the angle of refraction.

Stick two pins on the incident ray. Light rays reflected on the pins will pass through the glass block. Then we search for the images of the two pins on the other side of the glass block. Come and watch the images on the other side of the glass block. Do you see the images of the pins? Then the next thing you do is to find by using two other pins the images of the first two pins so that they coincide. You will first of all see an image; then you will use it to locate the second image. After that, remove the glass block and join the points of the two searching pins so that they touch the lower side of the glass block outline.

Draw the normal through the glass block outline because the angles of incidence and refraction are measured from it. Join the two refracted points. The angles are now well defined.

This procedure is repeated for other angles of incidence and you will get resulting angles of refraction. You will have to do this in the lab; this is just a demonstration. As we go along in the lab I will explain to you better.

Now let me show you how we tabulate the results. For each angle of incidence, you will have an angle of refraction; then you will have sine of the angle of incidence and sine of the angle of refraction.

i	r	sin i	sin r	sin i/sin r

You can then plot the values of sin i against sin r. If you are accurate enough you will get a straight line graph passing through the origin. If the graph is a straight line passing through the origin, what type of relation is that? [Teacher draws a straight line graph on the blackboard.]

S: Direct relation.

B: Some students because of examination fright construct two separate tables. [Teacher illustrates by drawing two sample tables on the blackboard.] This is wrong. The table should be a composite one having all the values together. In all the experiments you do, make sure that you enter your readings in a composite table. The other important thing is in taking your readings, if for instance the angle of incidence is 32 degrees, it should be written as 32.0 degrees. Examiners penalize if you record your readings without the appropriate decimal points. The graph is a straight line because it is a direct variation, and so for all the values you take, the ratio of sin i to sin r will give you a constant value. The vales for the quotient of the ratio of sin i to sin r may vary, but you will have to find the mean value of all the values. The next important thing is how to find the refractive index from graph. To find the refractive index you only need to find the slope of the graph. What is a slope?

S: The gradient.

B: The gradient in that graph will be the rise in the sin r axis divided by the corresponding increase in distance along the sin i axis. This will be the experiment you will be doing during our next practical.

As the preceding dialogue suggests, the practical involved measurement of the refractive index of a glass block. (Four of the school's seven rectangular glass blocks were chipped on the edges.) Students were organised into nine groups, eight groups with five students in each and one group with six students. A leader for each group was appointed; his duties were to control the use of the available materials for the practicals, copy instructions as the teacher dictates in front of the class, see that every student in the group participates in the practical, and copy the results of the practical on the blackboard for analysis. Other members in each group copied the ray diagrams from the blackboard into their exercise books. Every member of the group took part in setting up the practical; some put more effort in the work than others. Some students moved from one group to another, watching how they did their work and going back to show other members in their group what to do. About 20 minutes before the end of the practical class, each group leader copied their results on the blackboard. Then Teacher B calculated the refractive index and compared the results for each group. Students were expected to go over the calculations in the analysis on their own. Students do not prepare written reports of the practicals.

At the end of the practical class Teacher B identified two students whom the researcher interviewed separately to explore the extent to which they understood what they were doing and to get their views about the practicals they do at school. The students were group leaders; one of the interviews is reported below.

Interview with a Student after a Practical Class

JK: What was the practical about?

S: The practical was about refractive index of a rectangular glass block.

JK: What were you required to investigate in this practical ?

S: We were required to calculate the angle of incidence and the angle of refraction.

JK: Did you get some readings ?

S: Yes, we got values like 28 degrees as the angle of incidence and 18 degrees as the angle of refraction. But they were not that accurate.

JK: How do you know that those values are not accurate?

S: The size of the group does not permit one to take accurate readings because every other person in the group is pushing the other in order to watch for the image. These movements and pushing around the instrument does not permit the group to get accurate readings.

JK: Suppose you were working alone with the instruments, which area would you have problems with?

S: My problem will be in finding the angle of refraction. Because if you stick pin one and two, you have to move to the other side to trace the image of the two pins before you stick the other two pins. It is difficult to determine the exact position of the images of the first two pins because they seem to be in a straight line with the searching pins from any point on the lower surface of the glass block. My problem was determining the exact position of the emergent ray in order to determine the angle of refraction.

JK: How are you going to analyse the values you have recorded?

S: The values can only be analysed if tables of values are provided. The values should be entered in the tables and then calculated.

JK: Based on the practical that you have just done, how are you going to analyse your values in order to provide an answer to your investigation?

S: It depends on the accuracy of the values.

JK: Suppose the values are accurate, how would you use them to provide an answer to your investigation?

S: Then the value of the refractive index of air to glass will be given, then you will use the relationship of sin i divided by sin r.

JK: Can you think of another way of analyzing your data?

S: That is the only way so far that I have been instructed in.

JK: Didn't your teacher talk about using a graph to analyse your data?

S: Oh yes, you can use a graph. You will also be asked to draw a straight line graph.

JK: How will you get the refractive index of the glass block from the graph?

S: I will have to go and look it up in my text.

JK: Will you have problems in plotting your values on the graph?

S: No.

JK: Do you have any problems that you could discuss with me?

S: We have got many difficulties. In the first place the number of glass blocks were not enough for the number of students in class. Secondly,

we have been organized in groups of five and I had difficulty in understanding how to carry out the practical. Even some members of my group did not understand the aspects involved in the practical. Some members in the group did not take the work seriously because they attend private lessons after school; they cause noise in class to distract our attention.

JK: How did you get your values when you did not understand how to carry out the practical?

S: A friend from another group came over to assist us. He is attending a private lesson.

After observing two lessons and demonstrations, observing students do a practical in groups of five in the laboratory, and conducting two interviews each with two students, an interview was also conducted with Teacher B. The purpose was to elicit the teacher's views on physics practicals and on the teaching of physics as a subject, to cross check issues raised by the two students and to better understand the observations made in the classroom and the laboratory. In this interview, Teacher B suggests that practical work contributes to understanding concepts and to seeing the "practical" side of physics as a subject. Yet the discussion of students' difficulty in following instructions suggests an alternative view, one that assumes that understanding follows from reading and being told.

Interview with Teacher B

JK: How are students selected to study physics?

B: In this school students are selected on the basis of their performance

in physics in the previous form. For instance when students get to form IV, senior teachers in the physics department look at records to see how well a student has been doing in physics. Of course not only in physics but in mathematics and other science subjects so that they could be streamed. In the area of physics, we look at the student's grade in the previous form.

JK: Why do students do physics practical?

B: In my mind I think they do these practicals so that they could better understand the concepts in physics. The practicals tie up students' theoretical knowledge with the understanding they get from playing with the materials in the lab. Without this I don't think there will be any holistic understanding of the subject.

JK: How often do students do practicals?

B: On the average in this class which I teach, they do practicals once a week, but since we have a double period it covers both practical and theory that time. But we are handicapped by the unavailability of materials. I would like to see the boys do practicals about three times a week at least because the practicals are so important that it makes the students understand the theoretical part better. I only conduct practicals once a week. Actually it should have been more than that but due to the unavailability of materials we cannot do otherwise.

JK: In one of the practicals students worked in groups of five and in the other practical you did a demonstration while students crowded around you. Would you like to explain the difference in methods?

B: Yes, exactly, that points to the fact that we do not have basic materials like rectangular glass blocks and triangular glass prisms. The demonstration was intended to give students an insight of what the practical involved so that when they go to other schools for extra work or find materials later on to do the practical themselves they will be able to do the practical better. It is very difficult for me right now to conduct a practical the way it should be conducted.

JK: Why do students go to other schools to do practicals?

B: Well, there may be personal reasons from the students, but I think that they go to other schools because they have more materials than our school. In these schools students do private work and they get the actual feel with the materials.

JK: Do you by chance know whether students pay for the private work in these schools?

B: I am pretty sure that they do pay because I could not imagine a teacher giving extra work to students as charity.

JK: With the few practicals your students have been doing, which aspects do they have difficulty with?

B: The difficulties they face sometime arise from their misunderstanding of the instructions. I believe some of them do not understand the instructions, they just jump on doing the practicals and so they have to go back and forth reading the instructions, whereas if they have understood the instructions earlier they should be able to do the practicals. And also you cannot remove the fact that some of them do

not yet know the equipment we have in the lab, how it works and how it should be set up, etc. They know the basic equipment but I wonder if they know how to use the micrometer screw gauge and the vernier caliper for instance. They have studied how they operate and their uses in the lower forms but since we do not have any in the lab presently I doubt if they know how to use them. The students know about them theoretically but they may not have seen them. That is one of my fears about students studying physics up to form V in this school. Students should know about these basic instruments, how they work and how to use them.

JK: Could you explain what you mean by "they just jump on doing the practicals"?

B: Most times in the lab we use the same or similar materials and instruments to explain different concepts. So when students see the same materials and instruments they may think that they have been asked to do what they have been doing in class. Without reading the instructions properly they go on doing different things from what they have been asked to do.

JK: How often do students "just jump on doing the practicals"?

B: As often as they do practicals. I always tell them to read the instructions first before proceeding with any activity.

JK: How do you hope to get students to develop the practice of reading instructions before starting to work on practicals?

B: I hope to continue telling them to read the instructions before beginning any practical work.

JK: Besides the understanding of theory and getting grips on underlying concepts, do you conduct physics practicals with another intention?

B: Yes, I conduct physics practicals because I believe that by so doing the students will actually know that physics is not only a theoretical subject. In fact I feel that when I do practicals my main theme is to make sure that, whatever the case may be, the students should know that the subject is a practical one and it should be applied within our environment. However, we should be able to explain concepts practically.

JK: Do you also conduct physics practicals with the intention of preparing students for the G.C.E. "O" level physics practical examination?

B: Yes. In fact that is one of the main reasons, especially when students get to form V. Even in form IV the practicals are also geared towards the examination but they are more general in nature with the intention of getting to become familiar with the use of the equipment and materials.

JK: If there were no public examination, would you conduct physics practicals differently?

B: Well, yes, to some extent. There are certain practicals which students could do at home but since I am constrained by the public examination I conduct practicals that students will need for the examination. So if there was no physics practical examination I should

have diversified the practicals we do in form V and would spend some time on how to interpret experimental results meaningfully.

JK: Then what type of practicals do students perform in form V?

B: Practicals that are geared towards the G.C.E. "O" level physics practical examination.

JK: How do students relate the theory taught in class to the practicals they do?

B: After the practicals they are expected to interpret the results by way of drawing graphs and interpreting the graphs. For instance they might be able to find out that they learned in the theory class that the refractive index of glass is about 1.50, which is the theoretical value. If they perform an experiment in determining the refractive index of glass and they come up with a value close to that, then they know that they have proved what they learned in theory. Through practicals students can also find out that different glass materials have different refractive indices, which will prove the point that the speed of light varies in different materials.

JK: How would you describe the G.C.E. "O"level physics practical examination?

B: From the G.C.E. "O" level physics syllabus, one will see that the examination tests whether the students have been adequately prepared to study physics at the university or college. It still remains for us teachers to show the students that the knowledge of physics has to be

acquired not only for the examination or to go to university but could be useful to their environment.

JK: I observed that there were not enough instruments and materials for students to work with. How do you cope with this shortage, especially when you conduct the G.C.E. "O" level physics practical examination?

B: At the nick of time for the physics practical examination, I ask the principal to buy instruments and materials that are available locally. Others that cannot be bought locally can be got either from other schools or the university and college.

JK: How do you know which instruments and materials the principal should buy or get from other schools or university or college?

B: The examination council sends confidential instructions of materials and instruments required for the examination to the principal of the school. The principal in turn hands over the instructions to the teacher teaching physics in form V. The teacher then checks for the instruments and materials he has in his lab and those he does not have. It is from the confidential instructions that we know which materials and instruments to either buy or borrow.

JK: Is the shortage of instruments common to all the schools doing physics?

B: Yes. Some schools may have some materials and instruments. I am sure no school in the Western Area has everything in the laboratory. Some schools do not have any instrument in their laboratories.

JK: Does that mean that students in these schools do not do practicals in their regular classes?

B: Yes. In some of these schools teachers teach theory all the time because of the unavailability of instruments and materials.

JK: How then are students prepared for the G.C.E. "O" level physics practical examination?

B: In most of the schools practical classes are conducted only a few weeks before the examination. Students are drilled for the practical examination after teachers have seen the instructions required for the practical examination.

JK: Could you suggest reasons why some students that pass the G.C.E. "O" level physics examination do not perform well in practicals at college?

B: The process of acquiring knowledge in physics is not discrete but continuous. One has to start from the basic, then to the complex. If you have learned how to use an instrument, perhaps doing a practical might only involve a fraction of the knowledge you know about the instrument to get the result. So if you do not get the fundamentals earlier then you will eventually end up not being able to do much in practicals. If you have a crash program of practicals in schools so that the students can answer the practical questions, then they will not get the understanding of how to do practicals. This is why students face a lot of difficulties when they go to college. So if you learn to do an experiment so that you can answer a particular question in the exams, that does not necessarily

mean that you have actually acquired the necessary skills. The most important point is that students must acquire the fundamental skills and be able to use them later; otherwise students might end up passing the exams with good grades but unable to perform similar experiments at a later date.

JK: Do you think that diagrams assist students to follow instructions or do they create problems in practical physics?

B: They help a lot because in physics, as in biology, chemistry, and geography, diagrams play a very good role. Our students face a lot of difficulties trying to interpret things in English; if they have diagrams that represent concepts, then that will assist understanding. For instance, diagrams in electricity representing rheostat, key, ammeter, and voltmeter in practicals go a long way to help students follow instructions. If instructions are only written in English without diagrams, then students will be faced with greater problems. Diagrams go a long way to assist students to follow instructions and to conceptualize what they are required to investigate in practicals.

JK: If you were asked to prepare the G.C.E. "O" level physics practical examination, what type of questions will you set?

B: I will set short-answer questions and a practical, of course. But the practical will involve short procedures that will require students to write down their results for every step accomplished and finally the students will use the results to do an investigation. The present practical questions include all the necessary instructions but these instructions

should be in steps so that the student will know what he is required to do and measure. The instructions should involve short steps written in sequence so that students can easily follow.

JK: What are your views about physics teachers in general?

B: Physics teachers in Sierra Leone find it difficult to work in an environment where they do not have visual aids. Teachers face numerous problems, for example, the problem of getting equipment and materials and funds to buy materials that could be got locally. The majority of physics teachers want to leave teaching for other professions. Teaching physics is very interesting but if the conditions under which you are working are not favorable as compared to other jobs, then you end up not doing much. Physics teachers do not get job satisfaction because of the prevailing conditions in the schools of not having materials and equipment to work with and getting salary at the end of the month is not certain. Physics teachers should be more receptive to their students because we are losing a lot of them. The long term effect will be that there will be no students studying physics at the university and college. If physics teachers impart the necessary fundamentals to their students so that they become well grounded in physics in the secondary schools, then students will build on that foundation when they go to university or college. Physics teachers are very few, and teachers have to do part-time teaching in other schools so that these schools get the services of a physics teacher. A few engineers waiting for jobs are employed to teach physics in some

schools. These engineers face a lot of problems in the classroom because they were not trained to teach physics.

This interview with Teacher B completes the report of data from School B. The chapter concludes with presentation of data from School C.

Physics Teaching at School C

Physics classes were held on Friday afternoons (2:30-4:00 p.m.) and Saturday afternoons (12:00-2:00 p.m.). Students in forms IV and V attended those classes; students from other schools also attended these classes that were held after regular school hours. Facilities to conduct practicals in forms IV and V are not adequate in this school either. However, the few materials and equipment available in the laboratory are well cared for. Two sets of practicals were performed over a period of two weeks. One set of practicals was on optics (measurement of the refractive index of a rectangular glass block) and the other was on mechanics (the simple pendulum). Students attending school C performed the set of practicals in optics while students from other schools performed the set on mechanics.

In both lessons observed, the first 20 minutes were devoted to students from other schools working on practical work in mechanics. During this period Teacher C asked the rest of the class to read over the previous lesson while directing students in the mechanics group on how to proceed with the experiment. Almost every student in this set has a practical manual. The lesson of the day always started with teaching of theory followed by practical work in which the students work in groups of four. The lessons were teacher-directed, with Teacher C giving explanations and notes.

Practical work for the rest of the class was scheduled for the last 30 minutes of the teaching period. Students were placed in groups of four with a group leader for every group. Each group was given the same set of past G.C.E. "O" level physics practical question papers to work on. Teacher C stood in front of the class reading the instructions to the question and directing students how to proceed with the practical. Description of observations students should make, precautions students should employ in order to get reasonable values, the number of significant figures to use to record values and how to analyse the results were explained by Teacher C. Teacher C also went round each group assisting them with the practical work. Students did not analyse their results during practicals but were told to analyse the results at home.

The same practicals were performed the following week but with little or no direction from the teacher. Each group leader gave the group's results, which were compared with the results of other groups. The students did not submit written reports of practical work. Two students at School C were interviewed, as at the other two schools; these interviews were not transcribed when it was realized that they did not add to the comments made by students at Schools A and B.

An interview was conducted with Teacher C in order to get his views about physics practicals, the teaching of physics practicals and the problems in teaching physics in general. An excerpt from the interview follows. Teacher C reveals a different tone than Teachers A and B; he is respected for the results his students achieve on the examination. He speaks of practical work reinforcing theory, and works to have the two occur at the same time. He displays high regard for the examination system as it is presently organized, and this suggests a high degree of

coherence within his teaching and between his teaching strategies and the examination system.

Interview with Teacher C

JK: How are students selected to study physics?

C: Students are selected based on their performance in mathematics and physics in form III.

JK: Why do students do physics practicals?

C: The practicals are usually conducted to reinforce the theory which may have been taught. There are times when both the theory and practicals are conducted at the same time.

JK: I observed that you conduct practicals and teach theory at the same time. Why do you use such a strategy?

C: I found out that putting some of these concepts with a practical approach makes it very easy for the students to understand the concepts rather than doing them in an abstract manner. The practicals normally make it possible for them to be part of the learning situation because they are kept busy trying to observe what is going on and some of these concepts can be brought out without the students being told.

JK: How often do students do practicals?

C: Well nearly every week. There are times when topics may not have many practicals. These are the times practicals are not done.

JK: Do students have difficulty in performing practicals?

C: Well, based on my observations, those who turn out to be very cooperative, who may have worked very hard during the course of the year, tend to have easy work over the practicals.

JK: Do you also conduct practicals with the intention of preparing students for the G.C.E. "O" level physics practical examination?

C: These practicals have two aspects—to reinforce the theory and to get them prepared for the examination.

JK: If there were no public examination will you conduct physics practicals differently?

C: I would be forced to conduct practicals in order to reinforce the theory but I believe that, having the public examination in mind, then some of these practicals are given an approach that will be geared towards passing the examination.

JK: How do students relate theory to practice in physics, and what part do practicals play in this process?

C: Most of these practicals are not only geared towards reinforcing the theory which has been taught but there are times when these practicals will bring out observations which they have come across in their everyday life. So it has a two-fold aspect—to bring out the theory which may have been taught in that particular period and to help them explain certain behaviour or phenomena which they may have come across outside of the classroom.

JK: What type of practicals do students perform?

C: Practicals are done on all areas in the teaching syllabus.

JK: How would you describe the G.C.E. "O" level physics practical examination?

C: As for the standard, I will say it is up to standard and the papers are well drawn and they are geared towards getting the students to exhibit their basic knowledge of the concepts which they may have learnt.

JK: A teacher said that his students have difficulty in reading and following instructions. Do you also observe such difficulty in your students?

C: Well I have observed students facing such problems, especially those who have not been having enough exposures during the course of the year. But with my own pupils I must admit that only a few face this problem, probably because of their intelligence level or inability to understand basic English. But ruling off those factors, I strongly feel that if students have been given enough practice over the course of the year, then reading the practical questions in the examination should not pose a problem.

JK: Teachers allege that not all schools conduct physics practicals regularly except when the G.C.E. "O" level physics practical examination is near. What is your view on that?

C: Well I must admit that in fact we discussed that problem when we had the last science teachers' meeting. Most schools keep the practicals until the dying minutes for the examination.

JK: If you are asked to set the G.C.E. "O" level physics practical examination, what type of questions would you set?

C: I will draw questions based on the format which has been carried out by the Exams Council which I consider to be very impressive.

JK: A problem observed in other schools is the availability of apparatus. Do you have problem in getting apparatus to conduct practicals?

C: Well when I first came we used to have that problem but having discussed the problem with the principal it was decided that the number of students doing physics should be reduced, because the main problem was getting enough instruments for the number of students taking the examination. So by reducing the number we have been able to conduct the examination without going out to search for instruments.

JK: Don't you think that limiting the number will reduce the number of students who may want to study physics?

C: I don't want to feel so because we often cater for average and above average students. We always ensure that those with average ability and those above are catered for; the extremely weak ones are normally left out.

JK: Some students wear coloured clothes while others have on the schools' uniform. Why the difference in dress?

C: Those with coloured clothes are students from other schools that come for coaching in physics practicals.

JK: Is the principal aware of that?

C: Of course he is aware about that. I discussed it with him before ever they started to attend my classes.

JK: Why do you combine form IV and V physics classes and teach them as one class?

C: This is because I only have two days to meet with both classes. I have arranged it so that both classes will benefit from these meetings. Imagine that students in form V are continuing with the physics syllabus while students in form IV have just started the syllabus. So if those in form IV move on to form V they will be studying other aspects of the syllabus while students coming into form IV will be beginning the syllabus. It is a circular method for both forms. Students in form IV always begin the syllabus from a different point while students in form V end the syllabus from another point.

JK: How long do you hope to continue with this method?

C: I must hasten to add that this is a temporary method.

JK: You hold your classes after normal school hours. Why the time difference from the rest of the school?

C: I discussed my new schedule with the principal and he agreed to it. I could have resigned my job as a physics teacher but there would have been nobody to replace me. In order to help the children I conduct my classes the times I do after attending lectures in the day.

JK: Don't you think that the children will be tired and feel bored after being in school since 8:00 a.m.?

C: I do think about them but there is nothing I can do. This is why I teach theory and practicals as the lessons progress so that the children will not feel bored and tired.

JK: What are your views about physics teachers in general?

C: It is a very sensitive issue. . . . There is a need for the university to produce more graduates in that particular area. Physics teachers have been quite few in number and this has affected the teaching of the subject in most schools. The majority of physics teachers want to leave because there are no incentives to keep them in the profession and I don't think that the reward they get as salary is comparable to the effort put in studying the subject.

This presentation of data concludes with a brief summary of features of practical work in physics at the three schools. In school A students worked individually on a rotational basis on every set of practicals. Teacher A gave notes on procedures about practicals and required the students to write a formal report on every practical but she did not discuss the results of the practicals with the students. In school B students assist with the provision of equipment for practicals and they work in groups of five. Teacher B gives revision lessons of the theory for the practical to be performed, followed by demonstration lessons. Teacher B analyses students' practical results; students do not write formal reports on practicals they perform. In school C classes are held after regular school hours. Physics classes for forms IV and V are scheduled for the same time and students from other schools also attend these classes. Practicals are conducted after the theory has been taught. Practicals from past question papers are performed by the students, first with much assistance and direction from Teacher C and later without much help from the teacher. Students work in groups and they do not write formal reports on the practicals they perform. Chapter 5 presents an analysis of the data.

CHAPTER 5

ANALYSIS AND INTERPRETATION OF THE DATA

This chapter analyses and interprets the data presented in Chapter 4. An account of what teachers say they would like to do in practical work is followed by descriptions of what they say actually happens in the laboratories. Then attention turns to the pressures and constraints that help to explain why teachers conduct practicals as they do and to the consequences that follow for their students.

Teachers' Goals for Practical Work

The teachers stated that practical work should improve students' understanding of concepts in physics and also provide an opportunity for students to work with materials and equipment, increasing their involvement in the learning situation. The three teachers stated their views on why students do physics practicals in the following ways.

A: Well to aid the theory, to give a better understanding of the theoretical aspect of the subject.

B: In my mind I think they do these practicals so that they could better understand the concepts in physics. The practicals tie up students' theoretical knowledge with the understanding they get from playing with the materials in the lab. Without this I don't think there will be any holistic understanding of the subject.

B: Yes, I conduct physics practicals because I believe that by so doing the students will actually know that physics is not only a theoretical

subject. In fact I feel that when I do practicals my main theme is to make sure that whatever the case may be, the students should know that the subject is a practical one and it should be applied within our environment. However, we should be able to explain concepts practically.

C: Practicals are usually conducted to reinforce the theory which may have been taught. There are times when both the theory and the practicals are conducted at the same time.

C: I found out that putting some of these concepts with a practical approach makes it very easy for the students to understand the concept rather than doing it in an abstract manner. Practicals normally make it possible for the students to be part of the learning situation, because they are kept busy trying to observe what is going on and some of these concepts can be brought out without even the students being told.

The teachers' goals and aspirations for practical work show interesting similarities to the arguments developed by science education researchers who have turned their attention to the role of the laboratory in the teaching of science. The teachers' responses suggests that the laboratory should provide the initial direct experiences that will bring out students' existing conceptions and permit the development of new concepts in subsequent teaching; this is similar to the arguments of Renner, Abrahim, and Birnie (1985). Through practical work students will be exposed to the experiences that are to be acquired and which should form the basis for expanding the observed phenomena into new understandings of concepts (Renner, 1982). Driver (1983) argued that after performing practicals, students

should be involved in discussion in order to develop the process of making sense of their practical experiences.

Renner's (1982) "Learning Theory B" described earlier is a teaching approach that is based on concept-building. This approach aims at mastery learning of content and guiding students to relate and expand their understandings of concepts. There are three major stages to this approach. The first stage involves exposing students to the phenomenon illustrating the concept using materials and instruments related to the subject. It is at this stage that teachers perform demonstrations illustrating the phenomenon without telling the students what the immediate result would be. The students' role at this stage is observing the phenomenon. The second stage involves allowing students to describe their observations, and students may use their intuitive ideas to describe the observations (Brook et al. 1984). Their intuitive description may be correct but lack the use of scientific terms and vocabularies that will succinctly describe the observed phenomenon. It is at this stage that teachers could intervene, introducing the generally accepted scientific vocabularies or terms and symbols describing the observed phenomenon underlying the concept. The final stage to this teaching approach involves providing experiences for the students to expand the meaning of the concept. This is the stage where practical work for the students comes in. Practical work becomes the process through which students should expand and build on their understanding of the concept. Students could further expand their understandings through reading from their textbook. Their problems in understanding the explanations given in their textbook should be reduced because they will be familiar with the scientific terms, and can visualize what is being explained because they have seen a demonstration

of it. This approach may fit Shymansky and Penick's (1979) description of the importance of laboratory practical work.

> The primary goal of the laboratory experience for the beginning science student should be to reinforce through concrete examples and direct manipulation of materials the same basic concepts presented as an abstraction in the lecture or text. Unless this happens or is facilitated, the lab may be a waste of time. (p. 195)

However, the following extracts from observations of teachers conducting practical work show that their instructional methods tend not to achieve their goals of concept-building through practical work.

How Teachers Conduct Practical Work

Though the teachers believe that practicals assist students to understand the theory, there are factors that constrain them from teaching practicals as they would like to. Perhaps the major constraint that influences their teaching method is the G.C.E. "O" physics practical examination. The teachers say that the practicals students do in forms IV and V are to prepare them for the physics practical examination. The teachers expressed this purpose of the practical work in the following ways:

> A: Yes. In fact that [preparation for the examination] is one of the main reasons especially when students get to form V. Even in form IV the practicals are also geared towards the examination but they are more general in nature with the intention of getting to become familiar with the use of the equipment and materials.

C: Practicals have two-fold aspects, to reinforce the theory and to get the students prepared for the exams.

The practicals students perform do not assist in illustrating and explaining concepts. The teachers teach specific skills on how to carry out formal investigations for the purpose of an examination. This involves teaching students to become acquainted with concepts and manipulate equipment so that the knowledge and skill derived from such practicals could be used only to pass the physics practical examination. The teachers described the type of practicals students do in these terms:

A: Right now I know there are a lot of schools where no practicals are conducted before the exams. Towards the exams they [teachers] get the students to do one or two practicals that they feel might come in the exams and that is it.

B: Practicals are geared towards the G.C.E. "O" level physics practical examination.

B: In most of these schools practical classes are conducted only a few weeks before the examination. Students are drilled for the practical examination after teachers have seen the instruments required for the practical examination.

C: Well, I must admit that in fact we discussed that [schools do not conduct physics practicals regularly] when we had the last Sierra Leone Association of Science Teachers meeting, that most of the practicals [in the schools] are kept until the dying minutes for the examination.

Teachers employed methods of instruction that facilitated achieving their major objective of preparing students for public examination. Teacher A provided her students with the opportunity to work independently with the instruments while conducting practicals. She only assisted students with their work when they asked her to do so. She reports that she does not discuss their work regularly because students neglect their work and the class is large, with about 20 students to teach and supervise. She believes that giving notes and extensive explanations promotes students' understanding of physics practicals and physics in general. She also believes that students should work independently, using their textbooks and finding resource materials from the library.

This method of instruction is what Renner (1982) refers to as "Learning Theory A," in which the teacher informs the students and then the students later verify what they have received from the teacher by performing experiments with known outcomes. The method of teaching theory and then later performing standard sets of practicals that require the verification of established results could be described as the "traditional" approach. In this approach students perform a standard sets of practicals from laboratory manuals. These manuals describe experiments and methods to either "determine" or "verify" standard physical constants. The students performed standard sets of practicals but without laboratory manuals. They used their textbooks to follow instructions for performing the limited number of practicals made available to them.

Renner's (1982) "Learning Theory A" is a teaching approach that aims at informing and giving students facts and basic principles which should be verified by using standard sets of laboratory experiments. The purpose of this approach is

specific: mastery of content. This approach is based on the belief that the teacher is the reservoir of knowledge, and the knowledge students possess depends upon what the teacher tells them. This belief is commom with institutions where the curriculum is examination-oriented, and the approach has three stages. The first stage is to inform the students what they should learn. In this stage the teacher lectures and dictates notes, describes standard practicals to verify the facts and basic principles students have been told about, and refers students to their textbooks. The role of students at this stage is to listen carefully and take dowm notes. In the second stage, students perform standard set of experiments to verify the facts and principles they have copied. It is at this stage that students are required to attach meaning to the underlying basic principles of the concepts that they have been given during the lecture stage. Unfortunately, most students have difficulty in relating the theory they have heard to the practical work they should do. The third stage in this teaching appraoch involves practicing to answer questions and solving problems from textbooks. The three teachers in this study used methods similar to Renner's (1982) "Learning Theory A" approach.

The method used by teachers in Schools B and C involved demonstration of the practical work students should do one day prior to the practical class. During these demonstrations the teachers told students everything they needed to know, including the expected results. This method of instruction, according to Raghubir (1979), deprives the students of the opportunity to learn for themselves. The students worked in groups (five in a group) when performing practicals, but group work does not provide an opportunity to observe students individually at work and it does not provide students with the opportunity to independently manipulate instruments.

Rather, group work encourages some members of the group to rely on others for the completion of a practical, thereby failing to acquire the appropriate skills. In addition, there were times when the teachers had to perform demonstrations in place of practical work because of the unavailability of equipment. The students believe that group work and demonstrations do not permit them to participate fully in their learning experiences. One student commented about the limitation group work places on him:

> S: Well, eh . . . yes, there would have been more concentration, participation and speed in performing the practical. Working with four other students reduced the rate at which I worked.

Pressures and Constraints on Practical Work

As mentioned earlier, one of the constraints that forces teachers to teach practicals in the ways described is the formal practical examination taken by students at the end of form V. In actual practice, the three teachers placed more emphasis on conducting practicals in order to prepare students for examination than on providing a means for understanding physics concepts. Teachers generally commence teaching the G.C.E. "O" level physics syllabus in form IV but do not conduct practicals until form V; in form IV, they only teach theory. This arrangement is said to permit more time for complete coverage of the syllabus. There may be an interval of six months between the time teachers present theory to the time students do practical work. This challenges the students to remember and link what they had first tried to understand in form IV to the practical work they are required to do in form V. Inevitably, the type of practicals teachers conduct in form V are those

that are most relevant to the examination. Teachers are limited to conducting only a few experiments in order to cover material required by the theory examination in the restricted time available to them. Below are some of the reasons teachers gave for giving less emphasis to practicals.

> A: But we are only starting the "O" level syllabus effectively in form IV. That means that we have about a year and a few months and that is not enough. We have to select those experiments we feel will likely come in the exams, concentrate on those, and just do one or two that are supposed to assist the theory the students learn.
>
> C: I will be forced to conduct practicals in order to reinforce the theory but I believe that having the public exams in mind, then some of these practicals are given approaches that will be geared towards passing the exams.

The other factor that constrained teachers from teaching practicals the way they would like is the shortage of equipment and materials to conduct practicals. Although the schools' laboratories are fairly well built, they lack basic instruments and materials to conduct practicals in forms IV and V (Sawyerr, 1969). The practical work students performed in form V was limited to those experiments for which equipment and materials could be found in the schools. In School B students had to go with rectangular glass blocks in order to have sufficient equipment to perform practicals. Students from other schools attended practical classes in School C because they did not have equipment and materials to do practical work in their schools. Lack of equipment and materials coupled with the number of students in each class in Schools B and C forced students to work in groups of five. Lack of

equipment caused Teacher B to conduct a demonstration in place of a scheduled practical. The teachers normally borrow instruments from the university and M M T C in order to conduct the formal practical examination, and the situation became very serious after November 1989. Some physics teachers from other parts of the country went to Freetown to borrow equipment from schools and colleges in order to prepare students for the June 1990 G.C.E "O" level physics practical examination (A. R. Jones, personal communication, May 28, 1990).

Consequences for Students

The teachers' concerns to complete the physics syllabus for the examination coupled with the limited availability of equipment and materials inhibit their effort to teach physics practicals the way they would like to. Students' expectations for the examination were high; their future educational careers depend on their success in the G.C.E. "O" level examination. In some instances, they were not satisfied with the approach adopted by their teachers; this led them to attend private lessons. They suggested that the methods employed by their teachers did not enable them to understand what they were doing in the practicals. They also felt that practical work should have started in form IV in order to acquire adequate practice with instruments and better understanding of how to do practicals. Their concerns were to do practicals that would give them practice in the skills of manipulating equipment and materials, and analysing data for the purpose of passing the examination.

The students experienced some difficulties in performing the few experiments observed. The students could explain what they were to investigate but they did not seem to understand what it involved. Explanations of their observations were based

on common sense rather than scientific reasoning (Brook, Briggs, Bell, & Driver, 1984). The students did not display understanding of basic scientific facts required for the work they were attempting. They could state the principles underlying the practicals but could not apply them to the investigations. They could manipulate instruments in order to vary measurements but could not explain the reasons for such variations, nor could they analyse their data. True to Driver's (1983) observation, the students do not discuss their experiences with the teachers after practical work. This appeared to contribute to the students' difficulties in making sense of the data, seeing the relationship between variables in performing practical work, and explaining their experimental results in relation to the underlying concepts. Selected excerpts from the data are given below to illustrate some of the inadequacies students demonstrated.

Students did not display understanding of basic scientific facts required for the experimental work. From the perspective of "theory first, then practice," students would be expected to learn certain concepts before attempting laboratory work. From the perspective of experimental activities as part of concept-building, one would not expect prior understanding. We can see in the following example how this is so.

Example (School A): Determining acceleration due to gravity

JK: I observed that you were varying an aspect of the pendulum when you were performing the practical. Which aspect were you varying?

S: The oscillation.

JK: What causes oscillation to vary?

S: The to and fro movement.

JK: What makes the to and fro movement to vary?

S: [No response]

Students could state the principles underlying the practicals but could not apply them to complete the analysis of their data. The following example illustrates this point.

Example (School A): Determining the specific heat capacity of a metal

JK: How do you hope to analyse your readings?

S: After you have got the mass of the solid, mass of the calorimeter, mass of calorimeter and water, the initial temperature of the water in the calorimeter and the temperature of mixture in the calorimeter, you subtract T1 from T2 so that you will get the temperature of the calorimeter.

JK: What were you investigating during the practical?

S: (No response)

This situation highlights the tension between theory-verification and concept-building as alternative purposes for laboratory work. When theory precedes experience, it is not surprising that difficulties arise in attaching that theory to practical situations. When experience precedes theory, the theory is developed in direct response to the experiences (Renner, 1982).

Students could follow instructions and manipulate instruments in order to vary measurements but they could not explain the reasons for such variations. In this particular experiment, there is considerable "conceptual distance" between the data that generally produce good results from a formula and the analysis of forces that explains the formula itself. When theory is presented first, without experience, it is

not surprising that students experience difficulties in explaining why they do particular manipulations. The following example illustrates this point.

Example (School A): Determining acceleration due to gravity

JK: Why do you have to measure time?

S: I measured time to find . . .

JK: Did you count the number of oscillations for each length?

S: No.

JK: Why do you have to measure oscillation and time?

S: In order to draw the graph.

The same student could not distinguish between the frequency and period of a pendulum swing, and this difficulty is again understandable when the distinction has been "learned" in theory rather than in practice.

Example (School A): Determining acceleration due to gravity

JK: What variables will you use to draw the graph?

S: The mean time, which is the periodic time and the number of oscillations.

When theory precedes experience, it is natural that students' efforts to analyse data will focus on obtaining a correct value that has already been "given" to them. This takes attention away from the process by which a strategy for interpreting data is found, applied, and judged to be adequate. The following example illustrates this point.

Example (School B): Determining the refractive index of a glass block

JK: How are you going to analyse the values you have recorded?

S: The values can only be analysed if tables of values are provided. The values should be entered in the tables and then calculated.

JK: Can you think of another way of analyzing your data?

S: That is the only way so far that I have been instructed in.

JK: Didn't your teacher talked about using a graph to analyse your data?

S: Oh yes, you can use a graph. You will also be asked to draw a straight line graph.

JK: How will you get the refractive index of the glass block from the graph?

S: I will have to go and look it up in my textbook.

Some of the students copied results from their friends. Very few students could associate calculation of the slope of a line as one of the ways experimental data can be analysed and that the slope gives an average value for the data collected.

In addition to the inadequacies observed, the students also admitted having difficulties in performing practicals. For example, the students had difficulty with locating the image of an object using search pins. According to Colton (1982), this was because students confuse ray diagram representation with the actual real representation of the object pins and the searching pins. Other types of difficulties students encountered were due to lack of appropriate content knowledge, lack of practice using equipment, and limited illustrations of scientific facts that they have been taught in schools. The following examples are illustrative.

Students confused ray diagram representation with actual real representation of the object pins and the searching pins. Here again, the explanation presented before experience interferes with the attempt to make sense of experience.

Example (School B): Determining the refractive index of a glass block

S: My problem will be in finding the angle of refraction. Because if you stick pin one and two, you have to move to the other side to trace the image of the two pins before you stick the other two pins. It is difficult to determine the exact position of the images of the first two pins because they seem to be in a straight line with the searching pins from any point on the lower surface of the glass block. My problem was determining the exact position of the emergent ray in order to determine the angle of refraction.

Students lack content knowledge, practice, and illustrations of scientific facts. When practice is verification of theory, students acquire vocabulary that the teacher assumes signifies understanding. Yet it is possible for very fundamental misunderstandings to persist until challenged by the practical context.

Example (School A): Determining the specific heat capacity of a metal

JK: Which aspects of the practical did you have problems with?

S: I did not know how to measure the temperature at first.

JK: What do you mean by "I did not know how to measure the temperature"?

S: That was my first time I measured the temperature of a liquid, so I did not know how to go about it.

Example (School A): Determining acceleration due to gravity

JK: What were your problems?

S: I did not know that I should find the time for one oscillation. I only measured T1 and T2.

S: I also had problem in counting the number of oscillations.

JK: Could you explain yourself further?

S: When you are swinging the pendulum you don't have to just swing it in a large scale, you just have to touch it a little bit in order to get an accurate result. So at times the pendulum will stop swinging when I still have not yet counted the number of oscillations. To be fair with you I did not understand anything in the practical.

Example (School B): Determining the refractive index of a glass block

S: My problems were how to get the refractive ray and the angle of refraction. I thought that the emergent ray was the refracted ray and the angle which it makes with the normal on the other side of the glass block was the angle of refraction.

These examples illustrate some of the difficulties experienced by students in their practical work in physics. What many teachers regard as basic and fundamental procedures are not easy for students to learn when time, equipment, and individual access to equipment are restricted.

However, these difficulties were not necessarily due to the students' lack of ability. Students put in the science streams in form IV in each of the schools are those with above average achievement in the sciences and mathematics in the lower forms. It is assumed that these students have acquired the fundamental principles that will enable them to comprehend basic scientific facts and mathematical relations if they are properly explained and demonstrated. Even the teachers know that the students' background in science are strong enough to permit them to develop the concepts and skills required for the G.C.E. "O" level physics practical examination.

Selection of students to study physics in form IV and subsequently in form V in the three schools were based on criteria that were outlined by the teachers.

A: Well usually after their third form they are streamed, invariably according to their performance in the different subjects. Those who are mathematically good and seem to have the aptitude for the sciences go into the science stream where it is automatic they have to do physics. The others are streamed into the arts, economics and commercial. So it is automatic they do physics in form IV if they have been streamed into the science stream.

B: In this school students are selected on the basis of their performance in physics in the previous form. For instance when students get to form IV, senior teachers in the physics department look at records to see how well a student has been doing in physics. Of course not only in physics but in mathematics and other science subjects so that they could be streamed. In the area of physics, we look at the students' grade in the previous form.

C: Students are selected to do physics based on their performances in mathematics and physics in form III.

Summary

This analysis and interpretation has described what the teachers would like practicals to be, presented a description of an adaptive application of Renner's (1982) "Learning Theory B" to physics practical instruction as an example of that concept-building approach, and described how teachers actually do conduct

physics practicals in their laboratories. The instructional methods the three participating teachers employed to conduct physics practicals have been interpreted in terms of Renner's (1982) "Learning Theory A," which describes theory-verification approach. The data were further analysed and interpreted in terms of the constraints that make teachers teach practicals as they do and the consequences that the students face because of the methods used to teach physics practicals. Generally, teachers have good intentions of conducting practicals as they teach theory in order to illustrate concepts and provide activities that promote student understanding. Because of the public examination and the amount of work that is required to cover the curriculum for that examination, teachers tend to put less emphasis on practicals. Teachers also made the point that shortages of equipment and materials, textbooks, and laboratory manuals make the teaching of physics in general a difficult task. As observed and reported, teachers drill their students in skills specific to the practical examination and guide them on topics expected to appear in the practical examination in order to compensate for general inadequacies in students' scientific skills and techniques. The practice of drilling students specifically for the practical examination helps to explain how students pass the G.C.E. "O" level physics practical examination but later demonstrate a broad range of inadequacies in the physics laboratory. The long-range consequences for students certainly seem undesirable, for they have passed an examination without acquiring the skills that the examination is intended to assess. Chapter 6 discusses the conclusions from the analysis and presents recomendations for further research.

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CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

The problem investigated in this study arises from the researcher's observations of laboratory work by students admitted into the first year physics programme at Milton Margai Teachers College in Sierra Leone. The researcher became concerned about the students' difficulties because the scientific skills and knowledge required for such practical work should have been acquired in the secondary school physics programme in order to pass the G.C.E. "O" level physics practical examination. Data provided by physics teachers and students at three secondary schools in Freetown, Sierra Leone, establish a basis for interpreting students' difficulties in learning to carry out and make sense of the results of practical work. The data are interpreted in the light of a number of studies related to the importance of practical work in science instruction with reference to Renner's (1982) Learning Theories A and B. The analysis is based on what the teachers would like practicals to be, how they conduct physics practicals, constraints that inhibit their efforts to teach practicals the way they would like to, and the consequences students face due to the methods used to conduct physics practicals.

This study has investigated how students in three secondary schools in Sierra Leone are taught physics practicals. The researcher used field notes, tape recording, and interviews to collect data from three teachers and 116 students who were being prepared for the G.C.E. "O" level physics practical examination in June 1990. The data reveal that physics practicals are not used to illustrate physical principles that enhance understanding of the underlying concepts. Physics

practicals are being taught as a "product" of learning science, a product that is to be tested by the public examination which students take after two years of studying physics. It appears that the three physics teachers observed in this study have developed strategies for practical work that enable students to pass the practical examination in G.C.E. "O" level physics without developing the skills that the examination is intended to assess. At least some of the students who pass the examination are unable to demonstrate the intended laboratory skills in other contexts away from the examination setting.

The study reveals that teachers who participated in this study, like science educators in many parts of the world, believe that practicals will help students understand physics concepts better and hence promote liking for the subject. However, their views seem to be rhetorical. In reality, practicals are rarely done in the schools, and the few that are performed are focussed on enabling students to pass their formal examination. The few and limited practicals students performed in form V do not provide opportunities to develop practical skills in science or to test and extend their understanding of physical concepts. The central purpose is to give students opportunities to develop the skills required by the practical examination; secondary purposes include illustrating theory and giving students some sense of how physics relates to everyday life.

The approach teachers employed in teaching physics practicals seems intended to ensure that they complete the physics syllabus for the examination within the limited time at their disposal in forms IV and V. The poor economic situation in the country means that schools do not have funds to buy or replenish equipment. Lack of equipment limits the types of practicals students can do and increases the

need for teachers to present demonstrations instead. These demonstrations were performed at the expense of practical work students could have accomplished on their own. Lack of resources and equipment required students to do practical work in groups of five and limited these opportunities to ones for which materials and equipment were available.

The approach physics teachers in Sierra Leone employ in presenting theory and practical work is highly sequential and could be described as following a "traditional" perspective. First there is a theory, and then there is the practical work, and the two are quite separate. Perhaps unintentionally, teachers' actions have led students to believe that the basic role of practical work is to illustrate theory that they were to learn when it was presented by the teacher outside the context of practical work. Two of the most obvious pressures that sustain this traditional perspective are the extensive physics content within the curriculum and the emphasis on memory as a learning strategy for preparing to take an elaborate formal examination.

Illustration of theory is only one role of practical work, and some would argue that it is a minor role. There is potential for a dynamic and interactive relationship between theory and practical work, although it seems rarely realized in science classrooms. Renner (1982) worked to capture this potential by describing two learning theories (A and B) for which the essential difference is the timing of experience. By having practical experience precede presentation of theory, students have opportunities to gain access to their present conceptions of the topic and they have personal experiences from which concepts may be "invented." Such an approach acknowledges the role of experience in the learning process and

challenges the familiar tell-listen-remember sequence often associated with schooling.

As science education researchers and others have argued on numerous occasions, both theory presentation and practical work have important roles to play in effective physics teaching. In the context of an extensive curriculum content leading to a formal examination, theory presentation has traditionally held the "upper hand." This study shows that physics teachers in Sierra Leone are no exceptions to this rule. It also shows that they maintain this approach to physics teaching despite severe economic constraints that not only limit the availability of equipment and but also threaten their personal survival.

The data reported in this study were collected at a time of difficult economic circumstances in Sierra Leone. Teachers' salaries are low, relative to the cost of living, and their salaries are not paid regularly. As expected, these circumstances affect the teachers' work, yet it is impressive that their work continues at the observed levels. The observed practical activities can be interpreted as "constrained versions" of the teaching that might be observed in a stronger economic climate. More importantly, there is no reason to assume that higher or more regular salaries would cause the teachers' conduct of practical work to be different *in kind* from what was observed in this study.

Another point worth noting concerns the manner in which the physics practical examination is conducted. The setting of the exam reinforces the perspective that the practical is not as important as the theory, or even directly related to theory. As soon as students feel that one aspect is less important, then they begin to put less time and effort in that aspect with a view to reducing their workload. The manner in

which teachers teach suggests that theory is more important than practical work. When the physics teachers receive confidential instructions about the equipment and materials needed for the examination, they can make very close guesses about the questions that will appear in the examination. Since teachers can make such guesses every year, there is even less incentive for them to give time to practical activities during routine school work. If teachers do adapt their final lessons with students according to what they expect will appear on the examination, there is no intention here to criticize them for doing so. The situation presents a genuine dilemma for teaching, and those teachers who direct their students to likely practical work are continuing their sincere efforts to help students pass the examination in physics.

Implications for Practice and Research

When one studies an educational setting so dominated by formal examinations, implications drawn from the study must, inevitably, be cast in terms of the presence and absence of such examinations. As long as the teaching of physics in Sierra Leone continues to be dominated by pressures to pass formal examinations, we can expect little change from the situations apparent in the study's data. The teachers and their students can be commended for making the best of very difficult circumstances. The fact that each of the three teachers could quickly state changes that they would make if there were no examinations underlines the significance of the examination system in their work.

While the practical examination in physics persists, it could be helpful to formalize the sophisticated informal network that enables the teachers to gain

access to the equipment that will be required for the examination. One is even tempted to suggest that the last-minute coaching for the equipment required could be organized and co-ordinated, though this would hardly be seen in a favourable light by the Examinations Council. Formal workshops for teachers on the nature and purpose of practical work in physics could focus on ways of assisting students with the most common difficulties they face in interpreting instructions and manipulating equipment.

Within the constraints of the examination system, it could be very productive to develop a modified practical examination that did not involve the manipulation of equipment. Considerable insight into the nature of students' difficulties in learning to manipulate equipment might be gained by devising paper-and-pencil questions that test students' understanding of practical work. Experimental data could be reported for students to manipulate and interpret. Students could be asked to describe experimental procedures for exploring a particular set of concepts in physics. Such a modified examination would reduce the search for specific equipment and would eliminate the guessing done by teachers once the equipment list has arrived. This is not to suggest that practical work should receive even less time, but to note that the present circumstances generate unfortunate circumstances such as the initial observation that students cannot display practical skills required for the examination they have passed.

If there were no practical examination, then there would be a significant and genuine opportunity to re-think the relationship between theoretical and practical work in the teaching of physics. It is always tempting to suggest familiar in-service education strategies of workshops and short courses for teachers, and in the present

context of education in Sierra Leone, these would indeed be welcomed. However, there is little reason to assume that familiar strategies would address the more fundamental issue that has been raised in this study. The data from interviews of teachers and students and from observations of physics practical activities provide new insight into the issue of acquiring laboratory skills. The teachers use a familiar "theory first, practice later" sequence that suits the covering of content and preparation for the examinations. Although none of the teachers would suggest that understanding is not a major goal, the priority given to preparation for the practical examination signals in subtle but clear fashion to the students that long-term understanding is *not* an issue. The interpretation of the data in terms of the issue of sequence of instruction (tell, then verify vs. observe, then invent) suggests that the limited practical work done by physics students in Sierra Leone is unlikely to develop lasting skills that can be demonstrated in other, non-examination contexts. Thus students may well pass the examination that is intended to confirm the development of skills that they actually have not developed.

All three participating teachers complained about the limited time available to complete the G.C.E. "O" level physics syllabus. There are two possible explanations to this complaint. One explanation could be that there is too much subject matter to be covered in the physics syllabus. The other explanation could be that the teachers tend to regard each topic in the syllabus in isolation and hence teach topics separately instead of relating each topic to the other in order to understand and interpret physical phenomena better. The complaint about insufficient time to complete the physics syllabus signals the need to investigate whether the content of the physics syllabus is too extensive to be covered within the available two years.

This problem could be investigated with a questionnaire to science teachers in Sierra Leone and across West Africa. The findings of this investigation could lead either to maintaining the syllabus with curriculum guidelines or to reducing some of the content without affecting the standard students should achieve in order to study physics and related science subjects in the university.

Beyond the issue of the sheer size of the physics syllabus, there is a pressing need to write curriculum guidelines for the teaching of physics in secondary schools. Most teachers go through the G.C.E. "O" level syllabus treating one topic after another. Curriculum guidelines could spell out the aims of teaching each topic in physics. The guidelines could be arranged into core units and the time allocation for each unit could be suggested. This could act as a guide in helping teachers devote the appropriate amount of time to each unit, and would be particularly useful to teachers with limited backgrounds in physics. The curriculum guidelines could arrange the units in related sequence so that both teachers and students would be better able to see how each unit is related to the others. Each unit could recommend laboratory activities for students and demonstrations to be performed by teachers. It would be very interesting to prepare guidelines that provided clear sequences of topics followed by teaching suggestions organized into two strands illustrating Theory A and Theory B. This could be one small beginning in the complex task of introducing Theory B to teachers who are completely comfortable with approaches consistent with Theory A.

The interpretation of the teachers' activities and methods and of the difficulties students encountered in performing physics practicals was based on Renner's (1982) Learning Theories A and B. This calls for a study that will compare both

teaching approaches. From the description of the teaching approaches to both theories, it has been assumed that Theory B is a better approach than Theory A. The proposed study would serve to explore the significance of that assumption in the Sierra Leone context. It might be possible to recruit teachers and students for a special in-service teaching institute held during the July-September break so that it would not interfere with regular school work and teachers and students would not feel constrained to follow Theory A because of the pressure to cover the syllabus. Here physics teachers and students could attempt to explore the meaning of teaching approaches consistent with Theory B, in order to better understand the potential advantages and the accompanying difficulties.

On my return to M M T C in Freetown, my work will involve not only teaching physics to pre-service teachers but also teaching science methods and supervising teaching practice. One immediate consequence of the findings of this study will be the introduction of methods and activities in my teaching that will promote better understanding in my students, including a personal exploration of the value of teaching carried out as suggested by Theory B. These methods and activities could be developed and practiced during the students' pre-service teaching practicum. If secondary school students are to develop the practice of understanding physical concepts through activities and demonstrations that illustrate the concept, such practice should begin in the lower forms. This is where students from M M T C will assist greatly because they are being prepared to teach physics in the lower forms of secondary schools in Sierra Leone.

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Appendix A. OBSERVATIONS AND INTERVIEWS AT SCHOOL B

The following are transcriptions of the lessons and demonstrations conducted a day prior to practical classes, the interviews with two students, and an interview with teacher B. These lessons were meant to recapitulate theories previously studied while the demonstrations illustrated the activities involved in the practical work.

First Lesson and Demonstration before a Group Practical Class

[The teaching transcription that follows concerns the refractive index of light and how to measure the refractive index of a rectangular glass block.]

B: We are going to look at the laws of refraction of light and how to measure the refractive index of light for a given medium. [The teacher draws a standard diagram for light passing through a glass block, bending toward the normal on entering and away from the normal on leaving.] Let mm' represent the boundary between the media - air and glass.

NO represents the normal to the plane.

AO - the incident ray

OB - the refracted ray

i - the angle of incidence

r - the angle of refraction

The angle between the normal and the incident ray is called the angle of incidence. The angle between the normal and the refracted ray is called the angle of refraction. The laws are

1. The incident ray, the refracted ray and the normal all lie on the same plane.
2. The ratio of the sin i to sin r is a constant.

This constant is called the refractive index from one medium to another; it is usually designated by n. Now let us look at refraction from another point of view. Who can define refraction in terms of the velocity of light from one medium with respect to another medium?

S-101: [inaudible].

B: Anybody else? Yes.

S-102: The velocity of light from less dense medium is greater than the velocity of light in the other medium.

B: Given two media, the ratio of the speed of light in medium one to the speed of light in medium two is a constant. It can also be defined as

$$\frac{\text{THE VELOCITY OF LIGHT IN MEDIUM ONE}}{\text{THE VELOCITY OF LIGHT IN MEDIUM TWO}} = \text{CONSTANT.}$$

At the end of this class you should know how to find the refractive index of a glass block. I will also explain to you how to find the refractive index using the idea of real and apparent depth. What happens when an object is immersed in water?

S-103: It increases in size.

B: Is that true?

S-104: No.

B: What actually happens?

S-105: It appears to be nearer.

B: It appears to be raised. So therefore you have an apparent depth and a real depth. What is an apparent depth?

S-106: [inaudible].

B: The apparent depth of an object is the depth of the object as it appears raised. [Teacher B sketches on the blackboard to explain the difference between real and apparent depth.] What is the real depth?

S-107: The actual depth of the object.

B: We all know how to read the meniscus of liquids. What is the shape of the meniscus of water?

S-1O8: Concave.

[Teacher draws diagram of an object immersed in water in a beaker on the blackboard]

B: The real depth is the distance from the object to the lower part of the meniscus. The apparent depth is distance of the image of the object as it appears raised inside the liquid (in this case, inside the beaker). So we can also define refractive index as the ratio of the depth to the apparent depth. Having arrived at these definitions of refractive index, the most important point I want you to note is how to find the refractive index of glass. What we have to do in the lab is how to find the refractive index of glass. In this case what will be the first medium?

S-1O9: Air.

B: What will be the second medium?

S-1O10: Glass.

B: I will demonstrate it to you. In any experiment you do, it is important that you read the instructions first. A lot of students fail the G.C.E. "O" level practical examination because they do not know what to do. They are not patient enough to read the instructions well. You put a piece of drawing paper on the drawing board. The first step is to draw the outline of the rectangular glass block. The whole idea is for us to be able to define an incident ray and then find the angle of incidence, from which we find the angle of refraction.

Stick two pins on the incident ray. Light rays reflected on the pins will pass through the glass block. Then we search for the images of the two pins on the other side of the glass block. Come and watch the images on the other side of the glass block. Do you see the images of the pins? Then the next thing you do is to find by using two other pins the images of the first two pins so that they coincide. You will first of all see an image; then you will use it to locate the second image. After that, remove the glass block and join the points of the two searching pins so that they touch the lower side of the glass block outline.

Draw the normal through the glass block outline because the angles of incidence and refraction are measured from it. Join the two refracted points. The angles are now well defined.

This procedure is repeated for other angles of incidence and you will get resulting angles of refraction. You will have to do this in the lab; this is just a demonstration. As we go along in the lab I will explain to you better.

Now let me show you how we tabulate the results. For each angle of incidence, you will have an angle of refraction; then you will have sine of the angle of incidence and sine of the angle of refraction.

i	r	sin i	sin r	sin i sin r

You can then plot the values of sin i against sin r. If you are accurate enough you will get a straight line graph passing through the origin. If the graph is a straight line passing through the origin, what type of relation is that? [Teacher draws straight line graph on the blackboard.]

S-1O11: Direct relation.

B: Some students because of examination fright construct two separate tables. [Teacher illustrates by drawing two sample tables on the blackboard.] This is wrong. The table should be a composite one having all the values together. In all the experiments you do, make sure that you enter your readings in a composite table. The other important thing is in taking your readings, if for instance the angle of incidence is 32 degrees, it should be written as 32.0 degrees. Examiners penalize if you record your readings without the appropriate decimal points. The graph is a straight line because it is a direct variation, and so for all the values you take, the ratio of sin i to sin r will give you a constant value. The values for the quotient of the ratio of sin i to sin r may vary, but you will have to find the mean value of all the values. The next important thing is how to find the refractive index from graph. To find the refractive index you only need to find the slope of the graph. What is a slope?

S-1O12: The gradient.

B: The gradient in that graph will be the rise in the sin r axis divided by the corresponding increase in distance along the sin i axis. This will be the experiment you will be doing during our next practical.

Interviews with Two Students after a Practical Class

[The transcription of the interviews with the two students follows. The practical work was conducted a day after the demonstration. Students worked in groups of five. Each group performed the same practical—measurement of the refractive index of a rectangular glass block. After the practical class, teacher B identified the two students. These students were in different groups and were interviewed separately. The interview seeks to determine the students' understanding of the practical work done and their views about the practicals they do at school.]

Interview with First Student

JK: What was the practical about?

S1: The practical was about refractive index of a rectangular glass block.

JK: What were you required to investigate in this practical?

S1: We were required to calculate the angle of incidence and the angle of refraction.

JK: Did you get some readings?

S1: Yes, we got values like 28 degrees as the angle of incidence and 18 degrees as the angle of refraction. But they were not that accurate.

JK: How do you know that those values are not accurate?

S1: The size of the group does not permit one to take accurate readings because every other person in the group is pushing the other in order to watch for the image. These movements and pushing around the instrument does not permit the group to get accurate readings.

JK: Suppose you were working alone with the instruments, which area would you have problems with?

S1: My problem will be in finding the angle of refraction. Because if you stick pin one and two, you have to move to the other side to trace the image of the two pins before you stick the other two pins. It is difficult to determine the exact position of the images of the first two pins because they seem to be in a straight line with the searching pins from any point on the lower surface of the glass block. My problem was determining the exact position of the emergent ray in order to determine the angle of refraction.

JK: How are you going to analyse the values you have recorded?

S1: The values can only be analysed if tables of values are provided. The values should be entered in the tables and then calculated.

JK: Based on the practical that you have just done, how are you going to analyse your values in order to provide an answer to your investigation?

S1: It depends on the accuracy of the values.

JK: Suppose the values are accurate, how would you use them to provide an answer to your investigation?

S1: Then the value of the refractive index of air to glass will be given, then you will use the relationship of sin i divided by sin r.

JK: Can you think of another way of analyzing your data?

S1: That is the only way so far that I have been instructed in.

JK: Didn't your teacher talk about using a graph to analyse your data?

S1: Oh yes, you can use a graph. You will also be asked to draw a straight line graph.

JK: How will you get the refractive index of the glass block from the graph?

S1: I will have to go and look it up in my text.

JK: Will you have problems in plotting your values on the graph?

S1: No.

JK: Do you have any problems that you could discuss with me?

S1: We have got many difficulties. In the first place the number of glass blocks were not enough for the number of students in class. Secondly, we have been organized in groups of five and I had difficulty in understanding how to carry out the practical. Even some members of my group did not understand the aspects involved in the practical. Some members in the group did not take the work seriously because they attend private lessons after school; they cause noise in class to distract our attention.

JK: How did you get your values when you did not understand how to carry out the practical?

S1: A friend from another group came over to assist us. He is attending a private lesson.

JK: Thank you.

Interview with Second Student

JK: What was the practical about?

S2: It was about finding the refractive index of a rectangular glass block.

JK: What were you required to do in this practical?

S2: We were required to find the angle of refraction and the angle of incidence and hence the refractive index of the glass.

JK: Did you have any difficulties in performing the practical?

S2: No.

JK: So there is no aspect of the practical that you had problems with?

S2: None at all.

JK: What would you say about the facilities in the laboratory?

S2: I don't know much about the laboratory because I have just began using it.

JK: Didn't you do any practical work in form IV?

S2: No, it was just theory and it is only now that the class has started doing practical.

JK: Would you say that you had sufficient materials to work with during the practical?

S2: Well, we were in groups of five and there were enough materials for each group.

JK: Don't you think that it would have been advantageous to work in smaller groups?

S2: Well, some people say that two heads are better than one, so I think that working on groups of five is the best way.

JK: Don't you think that working in groups of two would have provided enough participation for every member of that group?

S2: Well, yes, there would have been more concentration, participation and speed in performing the practical. Working with four other students reduced the rate at which I worked.

JK: How does that reduce the rate at which you work?

S2: Because everybody has to write his results and it takes more time for everybody to write down the same data than if everybody was working on his own. Again, everybody wants to take part in carrying out the investigation which may lead to repeating things that a member of the group would have done. And I had to spend time explaining how to focus the images of the pins to my friends.

JK: Which areas did you have problems with in doing the practical?

S2: My problems were how to get the refractive ray and the angle of refraction. I thought that the emergent ray was the refracted ray and the angle which it makes with the normal on the other side of the glass block was the angle of refraction.

JK: How did you over come the problems?

S2: The teacher came over to explain to me, he did a demonstration for the group and after that I was able to carry out the experiment.

JK: How are you going to analyse the values you have recorded?

S2: I will have to divide the sine of the angle of incidence by the sine of the angle of refraction for each set of values.

JK: Then you will end up having four values but you only need a value for the refractive index for the glass block.

S2: Yes, I will also have to find the average of the values?

JK: Why do you have to find the average?

S2: I am not quite sure why the teacher say we should.

JK: Is there another method of finding the refractive index of the glass block from the same set of values you have recorded?

S2: None that I can think of now.

JK: Didn't your teacher talked about plotting a graph?

S2: Oh yes, he did talk about a straight line graph as another way of analyzing the values. The graph should be sin i against sin r.

JK: If you were to plot the graph of sin i against sin r, what difficulty will you have?

S2: If the graph is not a straight line, then I will know that there was something wrong with the values recorded.

JK: Suppose all your measurements were correctly taken and recorded.

S2: I don't think I will have problems because I have been plotting similar graphs in mathematics. Maybe the problem I will get is to let the line pass through all the points.

JK: Is it a rule that the line must pass through all the points?

S2: Well, the mathematics teacher says that the points should be on the line.

JK: Ask your physics and mathematics teachers when next you meet them about plotting of straight line graphs.

JK: Why do you do physics practicals?

S2: Because it part of the West African Examination Council (W.A.E.C.) physics examination. It is good to practice for the examination.

JK: Besides the physics examination, are there any other reasons why you do physics practical?

S2: No, I can't think of any, because I want to be a medical doctor and I don't think that will be necessary for me in the future.

JK: So medical doctors do not need to do physics practicals?

S2: No, they don't need to do physics practicals, it is only biology and chemistry practicals.

JK: Don't you see any relationship in the physics practicals you perform now to what you intend to study in the future?

S2: Well, no.

JK: So there is no relevance of physics practicals to your future career, other than passing the physics examination?

S2: Yes, we only do practicals to practice for the examination.

JK: Thank you.

Second Lesson/Demonstration prior to Demonstration in the Laboratory

[The transcription of the second lesson and demonstration follows. The theory was on minimum deviation of light through a triangular glass prism and the demonstration was on the measurement of the angle of minimum deviation.]

B: The points we discussed in our last lesson were

> The greater the refractive index of light, the greater the minimum deviation.
>
> For a triangular glass prism, the greater the angle of the prism, also called the refracting angle, the greater the deviation.
>
> The greater the refractive index of glass used, the greater the minimum deviation.

Assuming that you already know what we mean by deviation, minimum deviation, angle of deviation and angle of minimum deviation, today we are going to talk about total internal reflection and then look at the next experiment we shall do tomorrow. Tomorrow we are going to look at how the angle of incidence is related to the angle of deviation. What did we say the relation was? The greater the angle of incidence, the smaller the angle of deviation. But there is a particular point which is reached in which the angle of deviation increases instead of decreasing and that

point is what we call the minimum deviation; And the angle so formed is called the angle of minimum deviation.

We are now going to study another phenomenon under refraction of light called total internal reflection. What is total internal reflection?

S: [inaudible].

B: When does it occur?

S: When the object is upright.

B: That does not explain the physics of the matter.

S: It occurs when the angle of incidence is greater than the angle of refraction.

B: Is that correct?

S1: No.

S2: When the angle of incidence is greater than the critical angle.

S: When the angle in the less dense medium is greater than the critical angle.

B: Anybody else?

S: When the angle of incidence is greater than the critical angle.

B: That is one condition.

S: When the refracted angle is 90 degrees.

B: Is that condition adequate enough?

S: When the refracted angle is more than 90 degrees.

B: We have come across a new idea called critical angle. What is meant by critical angle? In order to explain what total internal reflection is, we need to know what critical angle is. Let us look at the conditions necessary for total internal reflection:

1. The angle of incidence should be greater than the critical angle.
2. Light must travel from a dense medium to a less dense medium.

Now we should define what critical angle is. What is meant by critical angle?

S: It is the angle of incidence for which the angle of refraction is 90 degrees.

B: Total internal reflection occurs when the incidence angle is greater than the critical angle. Now let us look at the relationship between refractive index and critical angle. [Teacher copies relationship as is given in the textbook on the blackboard].

B: How do you call this prism? [Teacher holds up a triangular glass prism in front of the class].

S: Triangular glass prism.

B: Today what we are going to do is to find the minimum deviation of light. The first thing you do is to

1. Pin the drawing paper to the drawing board and draw the outline of the prism with a sharp pencil.
2. Use two optical pins to define the angle of incidence for which we shall find the corresponding angle of refraction.

The two pins are used only to define the angle of incidence. Make sure that they are in a straight line. Don't touch them because I know that they are straight already. Now have a look through the other side of the prism.

S: They are not straight.

B: You are not looking at the top part of the pins, you should look at the bottom of the prism. Are they straight?

S: Yes.

B: 3. The next thing is to find the images of the two pins using a search pin. Now look at the other side of the prism to find the images. Do you see the images?

S: Yes.

B: How many do you see?

S: One.

S: Two.

B: One or two, how many should you see?

S: One.

B: One, the other one should overlap. It is possible for you to see two if you actually bend down but you have to be careful for parallax. The next thing you do is to take two other pins. What do you do with the other pins?

S: You put them in line.

S: You put them in line with the image.

B: Make sure they coincide with the image formed by those two pins. Then mark the positions of the two pins and remove, then join the points. These are the precautions that you should note.

1. Make sure that the pencil is sharp.
2. The pins must be sufficiently spaced.
3. Make sure that you draw thin and straight lines.

You then draw the normals at the incidence and refractive rays respectively. Use the protractor to draw the normals because they should be perpendicular to the face of the prism. Yesterday we said that the angle of deviation is formed by the original and final direction of the incidence and refracted rays, which means that you have to extrapolate them or extend them. One of our major problems for the next practical is that we don't have enough prisms. So make sure you come with one. You will have to repeat the whole procedure for another angle of incidence. After taking about three to five readings, you then tabulate your readings as follows.

Angle of incidence Angle of deviation

1.

2.

3.

4.

5.

[This demonstration was done on a smaller table which was placed about the centre of the classroom. The students gathered in a circle around the demonstration table, but students on the outer part of the circle could hardly hear what the teacher was saying. Some students climbed on the tables in order to see what the teacher was doing. A few of the students left the classroom because they could not hear or see what the teacher was saying and doing.]

Laboratory Demonstration

[The exercise scheduled for the practical was determination of the minimum deviation of a triangular glass prism. This turned out to be a demonstration because there was only one triangular glass prism for a class of about 50 students. The instructions and diagram were written on the blackboard for the students to copy in their physics practical books. The students read the instructions as the teacher proceeded with the demonstration. Students surrounded the teacher in order to see what he was doing. Some students left the laboratory because they could not see nor participate in the demonstration. Some values were written on the blackboard but no analysis of theme was done. Students copied the values without any instructions from the teacher.]

Interview with First Student after the Demonstration

JK: What did the activities involve?

S1: They were about the refractive index from air to glass in the form of a triangular glass prism.

JK: Were they about finding the minimum deviation of a triangular glass prism?

S1: Yes, it was about the minimum deviation.

JK: What were you required to observe during the activities?

S1: We were not told to observe anything. That was the beginning of the practical and I have still not understood what the teacher was doing.

JK: How did you call the activities the teacher performed in the laboratory?

S1: It was a practical because the materials were not sufficient: so in order to understand the basic principles the teacher used the only available prism to do the practical and we all stood around and watched.

JK: What part did you play in the activities?

S1: Nothing. Everything was done by the teacher.

JK: Will you say that you did a practical in the laboratory?

S1: No, but I have told you that the teacher did the work. It was a demonstration we watched.

JK: When will you say that you did a practical in the laboratory?

S1: When we work in groups and we do the work for our self and the teacher comes to look what we are doing. Sometimes he will have to show us what to do.

JK: If I provide you with similar materials, will you repeat what you observed in the laboratory?

S1: I cannot perform it alone because I have not understood how to go about it. It was the teacher who did everything and I copied from the blackboard. He talks about to extrapolate in order to get the angle of minimum deviation. I do not know what that means and I did not see him do it because everybody was crowded around the table

JK: What would you say is the major problem in performing practicals in this school?

S1: One problem is the availability of practical equipment. We should have done this practical individually but it was a demonstration by the teacher. Some students have to wait until others have seen the demonstration and they later go to see the demonstration. All the explanation was done by the teacher. If enough equipment were available , we should have worked in smaller groups or individually and that would have given us the opportunity to do the work ourselves.

JK: What will say about the number of students in class?

S1: The number of students in the class is large, about 45 in number and we have only one triangular glass prism.

JK: What will you say about sitting accommodation in the laboratory?

S1: We stand all through practicals or demonstrations. There are no stools or chairs in the laboratory. But I think the fault is coming from the central government; the government is not particular about educational problems in the country. It is not only in the laboratory that we lack sitting accommodation, even in the classroom. Not all of the students have sitting accommodation during class times. When I was in form IV, some boys brought chairs from their homes to school so that they will sit during class times. For some who did not bring chairs, they cluster around on few tables causing noise in class. If you have to stand for more than an hour it will be difficult to pay attention.

JK: Tell me, why do you do physics practicals?

S1: Physics practicals help students understand physics theory. Without practicals it will be difficult to understand the main things involved in physics. Some schools do general science which makes it difficult for the students to understand the basic principles. These schools only do the introductory aspects of physics, chemistry and biology. For students who do pure science like physics are able to perform practical and are able to understand the subject matter better. We also do physics practical to prepare us for the G.C.E. practical examination.

JK: Will the practicals that you have been doing prepare you adequately for the G.C.E. physics practical examination?

S1: It will never assist a student to pass his examination. In the first place the equipment for the practicals are not available in the country all round. Secondly, the maintenance system in this school is very low. There should have been more than one teacher supervising practicals in a class of our size, and to collect equipment after practicals which are to be kept in a safe place. Then this school should not have run into the problem of not having enough equipment. So with this regard if all sets of demonstrations are conducted by a teacher then it is very difficult for a student to understand and as such will not pass his examination.

JK: How then do you hope to pass the G.C.E. physics practical examination?

S1: It all depends on a matter of chance. At least there are some variation in the number of equipment. For light, the equipment available are very limited. On other areas like mechanics, we have some equipment that are enough, relatively greater in number than those in light. So if the examination is based on areas in which we have more equipment than those with very little or no equipment, we the students will attempt questions on areas with more equipment because we would have done a similar experiment before.

JK: Do you hope to do more practicals before the examination?

S1: Yes, but it will be difficult to do all the practicals we require for the examination now because there is not much time left for the exams.

JK: What type of practicals will you be performing then?

S1: The teacher will select some practicals that are important for the examination and we will have to do most of the practicals in past question papers. In fact as from next term we will be doing practicals only from past question papers.

JK: Why do you have to use past questions to prepare for the examination?

S1: Well,they sometimes draw the same question only that they will ask you to do different thing. During this time everybody will try to be present because exams will be approaching.

JK: Will this be the time that students take their practicals seriously?

S1: Yes. We will be doing practicals the teacher thinks are important.

JK: How will the teacher tell which practicals are important from those which are not?

S1: Sir, the examination council thinks that all the schools are equally equipped with practical materials. So as a result the council sends instructions to the schools for materials they will need for the practical. So with this regard, schools do practicals around these materials. Experiments that involve the use of these materials are what we will be doing.

JK: How come that you know about the instructions the examination council sends?

S1: When I was in form IV I heard students talking about it and please sir almost every school will get the instruction if they are doing physics practical.

JK: Will you agree with me if I suggest that some students pass physics practicals because they are guided before the examination and not because they understand physics.

S1: Yes sir. It is also true that some schools teach physics practical during the examination. Few of the teachers do help students during the practical examination. Not all students are able enough to grasp the physics questions because so many things are there that they do not understand. But in terms of the examination, if teachers find out that the percentage of students doing well in the examination are less than the percentage not doing well, they tend to assist their students so that they will pass. That is one of the reasons why this school has introduced the system that when a student has a high distinction, and wants to do his sixth form; he has to take a test in order to get admission.

JK: You seem to be well informed about the physics practical examination. How come you know these facts?

S1: Because our friends tell us.

JK: Have these friends taken the physics practical examination before.

S1: Yes, some did well in the examination but others did not.

JK: How do you find your teach[illegible]ith regards to his teaching method?

S1: He is experienced in teaching physics. He is a graduate in physics. He taught us physics in form IV and now he is continuing with the class in form V. He hasn't got much problem with

us. Everything depends on the cooperation of the students and their attention paid in class because the teacher is very experienced.

JK: Thank you.

Interview with Second Student after the Demonstration

JK: What did you do in the lab?

S2: I was not present for the practical.

JK: Why were you not present?

S2: The place was too crowded and I could not see because I am short. Other students are taller than me and they were standing in front of me so I could not see.

JK: What was the teacher doing?

S2: He was demonstrating. The teacher did the demonstration. There wasn't enough equipment for the class to do practical. There was only one triangular glass prism. The teacher did all the talking and illustrations and even measured the values which we copied from the blackboard.

JK: Why did you leave the class?

S2: I could not concentrate, there was noise in the class and I had done it before.

JK: Where have you done it before?

S2: I have done it at my friend's home. He has a glass prism. We did it on our own at home.

JK: How will you describe the practicals that you do in school?

S2: Well, we do the theory first. We were suppose to be doing practicals in form IV, that is what I think and that is what everybody think. But teachers keep the practicals until when we are approaching the exams and we have to do everything in a hurry and there are no enough apparatus because of the country's economy. But the practicals we do are enough for us to pass the exams.

JK: Why do teachers keep the practicals until the examinations are approaching?

S2: Well, perhaps teachers think that we will remember better when it is nearer the examination. And also during this period we do practicals that the teacher considers very necessary for the examination.

[This student could not continue with the interview because his father came to collect him after school. The researcher made two appointments with this student in order to complete the interview but the student never turned up.]

Interview with Teacher B

[The transcribed interview with teacher B follows. The purpose was to get the teacher's views on physics practical work, to cross-check issues raised by students, to get an explanation on observations made in the classroom and the laboratory, and to discuss problems that affect the teaching of physics practicals in general.]

JK: How are students selected to study physics?

B: In this school students are selected on the basis of their performance in physics in the previous form. For instance when students get to form IV, senior teachers in the physics department look at records to see how well a student has been doing in physics. Of course not only in physics but in mathematics and other science subjects so that they could be streamed. In the area of physics, we look at the student's grade in the previous form.

JK: Why do students do physics practical?

B: In my mind I think they do these practicals so that they could better understand the concepts in physics. The practicals tie up students' theoretical knowledge with the understanding they get from playing with the materials in the lab. Without this I don't think there will be any wholistic understanding of the subject.

JK: How often do students do practicals?

B: On the average in this class which I teach, they do practicals once a week, but since we have a double period it covers both practical and theory that time. But we are handicapped by the

unavailability of materials. I would like to see the boys do practicals about three times a week at least because the practicals are so important that it makes the students understand the theoretical part better. I only conduct practicals once a week. Actually it should have been more than that but due to the unavailability of materials we cannot do otherwise.

JK: In one of the practicals students worked in groups of five and in the other practical you did a demonstration while students crowded around you. Would you like to explain the difference in methods?

B: Yes, exactly, that points to the fact that we do not have basic materials like rectangular glass blocks and triangular glass prisms. The demonstration was intended to give students an insight of what the practical involved so that when they go to other schools for extra work or find materials later on to do the practical themselves they will be able to do the practical better. It is very difficult for me right now to conduct a practical the way it should be conducted.

JK: Why do students go to other schools to do practicals?

B: Well, there may be personal reasons from the students, but I think that they go to other schools because they have more materials than our school. In these schools students do private work and they get the actual feel with the materials.

JK: Do you by chance know whether students pay for the private work in these schools?

B: I am pretty sure that they do pay because I could not imagine a teacher giving extra work to students as charity.

JK: With the few practicals your students have been doing, which aspects do they have difficulty with?

B: The difficulties they face sometime arise from their misunderstanding of the instructions. I believe some of them do not understand the instructions, they just jump on doing the practicals and so they have to go back and forth reading the instructions, whereas if they have understood the instructions earlier they should be able to do the practicals. And also you cannot remove the fact that some of them do not yet know the equipment we have in the lab, how they work and

how they should be set up, etc. They know the basic equipment but I wonder if they know how to use the micrometer screw gauge and the vernier caliper, for instance. They have studied how they operate and their uses in the lower forms but since we do not have any in the lab presently I doubt if they know how to use them. The students know about them theoretically but they may not have seen them. That is one of my fears about students studying physics up to form V in this school. Students should know about these basic instruments, how they work and how to use them.

JK: Could you explain what you mean by "they just jump on doing the practicals"?

B: Most times in the lab we use the same or similar materials and instruments to explain different concepts. So when students see the same materials and instruments they may think that they have been asked to do what they have been doing in class. Without reading the instructions properly they go on doing different things from what they have been asked to do.

JK: How often do students "just jump on doing the practicals"?

B: As often as they do practicals. I always tell them to read the instructions first before proceeding with any activity.

JK: How do you hope to get students to develop the practice of reading instructions before starting to work on practicals?

B: I hope to continue telling them to read the instructions before beginning any practical work.

JK: Besides the understanding of theory and getting grips on underlying concepts, do you conduct physics practicals with another intention?

B: Yes, I conduct physics practicals because I believe that by so doing the students will actually know that physics is not only a theoretical subject. In fact I feel that when I do practicals my main theme is to make sure that whatever the case may be, the students should know that the subject is a practical one and it should be applied within our environment. However, we should be able to explain concepts practically.

JK: Do you also conduct physics practicals with the intention of preparing students for the G.C.E. "O" level physics practical examination?

B: Yes. In fact that is one of the main reasons, especially when students get to form V. Even in form IV the practicals are also geared towards the examination but they are more general in nature with the intention of getting to become familiar with the use of the equipment and materials.

JK: If there were no public examination, would you conduct physics practicals differently?

B: Well, yes, to some extent. There are certain practicals which students could do at home but since I am constrained by the public examination I conduct practicals that students will need for the examination. So if there were no physics practical examination, I should have diversified the practicals we do in form V and would spend some time on how to interpret experimental results meaningfully.

JK: Then what type of practicals do students perform in form V?

B: Practicals that are geared towards the G.C.E. "O" level physics practical examination.

JK: How do students relate the theory taught in class to the practicals they do?

B: After the practicals they are expected to interpret the results by way of drawing graphs and interpreting the graphs. For instance they might be able to find out that they learnt in the theory class that the refractive index of glass is about 1.50, which is the theoretical value. If they perform an experiment in determining the refractive index of glass and they come up with a value close to that, then they know that they have proved what they learnt in theory. Through practicals students can also find out that different glass materials have different refractive indices, which will prove the point that the speed of light varies in different materials.

JK: How would you describe the G.C.E. "O"level physics practical examination?

B: From the G.C.E. "O" level physics syllabus, one will see that the examination tests whether the students have been adequately prepared to study physics at the university or college. It still remains for us teachers to show the students that the knowledge of physics has to be acquired not only for the examination or to go to university but could be useful to their environment.

JK: I observed that there were not enough instruments and materials for students to work with. How do you cope with this shortage, especially when you conduct the G.C.E. "O" level physics practical examination?

B: At the nick of time for the physics practical examination, I ask the principal to buy instruments and materials that are available locally. Others that cannot be bought locally can be got either from other schools or the university and college.

JK: How do you know which instruments and materials the principal should buy or get from other schools or university or college?

B: The examination council sends confidential instructions of materials and instruments required for the examination to the principal of the school. The principal in turn hands over the instructions to the teacher teaching physics in form V. The teacher then checks for the instruments and materials he has in his lab and those he does not have. It is from the confidential instructions that we know which materials and instruments to either buy or borrow.

JK: Is the shortage of instruments common to all the schools doing physics?

B: Yes. Some schools may have some materials and instruments. I am sure no school in the Western Area has everything in the laboratory. Some schools do not have any instrument in their laboratories.

JK: Does that mean that students in these schools do not do practicals in their regular classes?

B: Yes. In some of these schools teacher teach theory all the time because of the unavailability of instruments and materials.

JK: How then are students prepared for the G.C.E. "O" level physics practical examination?

B: In most of the schools practical classes are conducted only a few weeks before the examination. Students are drilled for the practical examination after teachers have seen the instructions required for the practical examination.

JK: Could you suggest reasons why some students that pass the G.C.E. "O" level physics examination do not perform well in practicals at college?

B: The process of acquiring knowledge in physics is not discrete but continuous. One has to start from the basic, then to the complex. If you have learnt how to use an instrument, perhaps doing a practical might only involve a fraction of the knowledge you know about the instrument to get the result. So if you do not get the fundamentals earlier then you will eventually end up not being able to do much in practicals. If you have a crash program of practicals in schools so that the students can answer the practical questions, then they will not get the understanding of how to do practicals. This is why students face a lot difficulties when they go to college. So if you learn to do an experiment so that you can answer a particular question in the exams, that does not necessary mean that you have actually acquired the necessary skills. The most important point is that students must acquire the fundamental skills and be able to use them later; otherwise students might end up passing the exams with good grades but unable to perform similar experiments at a later date.

JK: Do you think that diagrams assist students to follow instructions or do they create problems in practical physics?

B: They help a lot because in physics as in biology, chemistry, and geography, diagrams play a very good role. Our students face a lot of difficulties trying to interpret things in English; if they have diagrams that represent concepts, then that will assist understanding. For instance, diagrams in electricity representing rheostat, key, ammeter, and voltmeter in practicals go a long way to help students follow instructions. If instructions are only written in English without diagrams, then students will be faced with greater problems. Diagrams go a long way to assist students to follow instructions and to conceptualize what they are required to investigate in practicals.

JK: If you were asked to prepare the G.C.E. "O" level physics practical examination, what type of questions will you set?

B: I will set short-answer questions and a practical, of course. But the practical will involve short procedures that will require students to write down their results for every step accomplished and

finally the students will use the results to do an investigation. The present practical questions include all the necessary instructions but these instructions should be in steps so that the student will know what he is required to do and measure. The instructions should involve short steps written in sequence so that students can easily follow.

JK: What are your views about physics teachers in general?

B: Physics teachers in Sierra Leone find it difficult to work in an environment where they do not have visual aids. Teachers face numerous problems, for example, the problem of getting equipment and materials and funds to buy materials that could be got locally. The majority of physics teachers want to leave teaching for other professions. Teaching physics is very interesting but if the conditions under which you are working are not favorable as compared to other jobs, then you end up not doing much. Physics teachers do not get job satisfaction because of the prevailing conditions in the schools of not having materials and equipment to work with and getting salary at the end of the month is not certain. Physics teachers should be more receptive to their students because we are losing a lot of them. The long term effect will be that there will be no students studying physics at the university and college. If physics teachers impart the necessary fundamentals to their students so that they become well grounded in physics in the secondary schools, then students will build on that foundation when they go to university or college. Physics teachers are very few, and teachers have to do part-time teaching in other schools so that these schools get the services of a physics teacher. A few engineers waiting for jobs are employed to teach physics in some schools. These engineers face a lot of problems in the classroom because they were not trained to teach physics.

431/1/X June
S.C./G.C.E. 1990
PHYSICS 1
Practical
ALTERNATIVE A
INSTRUCTIONS
CONFIDENTIAL

A

WEST AFRICAN EXAMINATIONS COUNCIL

School Certificate and G.C.E.

PHYSICS 1

June 1990 PRACTICAL

Alternative A

Instructions to Supervisors

1. Great care should be taken to ensure that the information given below does not reach the candidates either directly or indirectly.

APPARATUS

2. In addition to the usual equipment of a Physics laboratory each candidate will require the following:

General

Mathematical tables;
Graph paper;
Geometrical instruments.

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Question 1

60° Triangular glass prism
Drawing board
Four drawing pins
Four optical pins
Two drawing sheets
Protractor
30 cm ruler

Question 2

2 V accumulator
One centre-zero galvanometer
One metre bridge
105 cm of bare constantan wire gauge s.w.g. 26 or 28
2 Ω standard resistor labelled R
Jockey
One plug key
Eight connecting wires
One crocodile clip

Question 3

A pair of vernier callipers
Weighing balance reading up to 0.10 g
About 150 ml of water in a beaker

One 250 ml glass beaker or a glass beaker of less capacity. A strip of graph paper of width 0.6 cm and length 6.0 cm graduated in cm. The strip should be marked clearly from 0–5 cm in interval of 1.0 cm. The strip should be attached carefully to the side of the beaker with gum or sellotape such that the depth of the liquid in the beaker can be measured directly.

CONDUCTING THE PRACTICAL PHYSICS TEST

3. The purpose of the practical Physics test is to find out whether the candidates can carry out simple practical work themselves. A candidate may sometimes be unable to show his/her practical ability through failure to understand some point in the theory of an experiment. In order to overcome this difficulty, you are requested to give (or to allow the Physics Teacher to give) a hint to a candidate who is unable to proceed.

4. The following regulations must be strictly adhered to.

(*a*) No hint may be announced to the candidates as a whole.

(*b*) A candidate who is unable to proceed and requires assistance must come up to you and state his or her difficulty. The candidates should be told that the Examiner will be informed of any assistance given in this way.

(*c*) A note must be made, on the Report Form, of any assistance given to any candidate, with the name and index number of the candidate.

5. It is suggested that the following announcement be made to the candidates at the beginning of the examination.

'The Examiners do not want you to waste your time because you cannot proceed with an experiment. Any candidate, therefore, who cannot continue with his/her experiment after he/she has spent a long time at it, may come to me and ask for help. I shall report to the Examiner any help given in this way, and some marks may be lost for the help.'

SUPERVISOR'S REPORT FORM

6. Supervisor's Report Forms are provided separately, on which you are requested to:

(*a*) supply detailed information about the apparatus where necessary

(*b*) report on any particular difficulties experienced by any candidate, especially if the Examiner would be unable to discover these from the written answers.

7. The candidates will be instructed not to write out a detailed description of the apparatus, but you, or the Physics Teacher, should state on the Report Form any difficulties which were experienced with the apparatus or any departure from the specified items which could not be avoided. In cases where several sets of apparatus are provided for a question and specific information about the apparatus is required by the Examiner, each piece of apparatus about which the information is required, and which may differ slightly for different candidates, must be clearly marked with letters A, B, C, etc., and the corresponding information must be clearly reported, showing which apparatus was supplied to which candidate. The candidates will be instructed to record these letters in their answer books.

8. The Report Form is also to be used for reporting on any assistance given to the candidates under the regulations explained in 4 above.

9. The Report Form should be signed by the Supervisor and by the person responsible for preparing the apparatus.

431/1 June
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PHYSICS 1
Practical
ALTERNATIVE A
$2\frac{3}{4}$ hours

A

WEST AFRICAN EXAMINATIONS COUNCIL

School Certificate and G.C.E.

PHYSICS 1

June 1990 PRACTICAL $2\frac{3}{4}$ hours

Alternative A

Answer two *questions* only.

You are required to record your observations as soon as they are made. The observations and any mathematical working and answers to questions should be written in your answer book; scrap paper must not be used. Attach your graphs to your answer book. You are not expected to copy out your work again neatly. The record may be kept in pencil provided it can be read clearly. If any piece of the apparatus provided has a label with a letter on it, this letter must be recorded in your answer book in order that the Examiner may identify which set of apparatus you used.

Neither a detailed description of the apparatus nor a full account of the method of carrying out the experiments is required. You should, however, note any special precautions you have taken and it must be clear (by diagrams or otherwise) exactly what the readings mean and how they were obtained.

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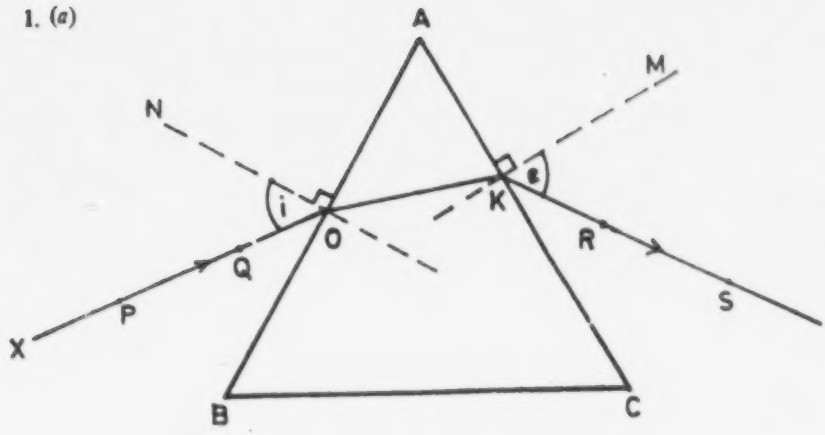
1. (*a*)



Place the triangular glass prism on the drawing paper and draw the outline *ABC* as shown above. Remove the prism. Mark a point *O* along *AB* and draw *ON* perpendicular to *AB*. Draw *OX* such that the angle of incidence *i* is 32°. Fix one pin at *P* and another at *Q* along *XO*. Replace the prism.

Fix one pin at *R* and another at *S* so that they are in a straight line with the pins at *P* and *Q* when viewed through the prism. Remove the pins and the prism. Join *RS* and produce it to meet *AC* at *K*. Draw the normal *KM* at *K* and measure the angle of emergence *e*.

Repeat the experiment four more times with values of $i = 37°, 42°, 47°$ and $52°$ and measure the corresponding values of *e*. Tabulate your readings. Plot the graph of $(i-e)$ on the vertical axis and *i* on the horizontal axis. Draw a smooth curve through the points. Determine from your graph the value *x* of the angle of incidence at which the graph intersects the horizontal axis. Calculate the value of 2 sin *x*. Using your graph, determine the value of $(i-e)$ when $i = 38°$ and hence find the value of *e*.

[24 marks]

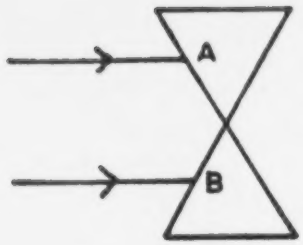
(*b*) (i) With the aid of a diagram, show one practical application of a right-angled triangular glass prism.

[2 marks]

(ii) A ray of light is incident on a glass block at an angle of 55°, what will be the angle of refraction if the refractive index of glass is 1.5 ?

[2 marks]

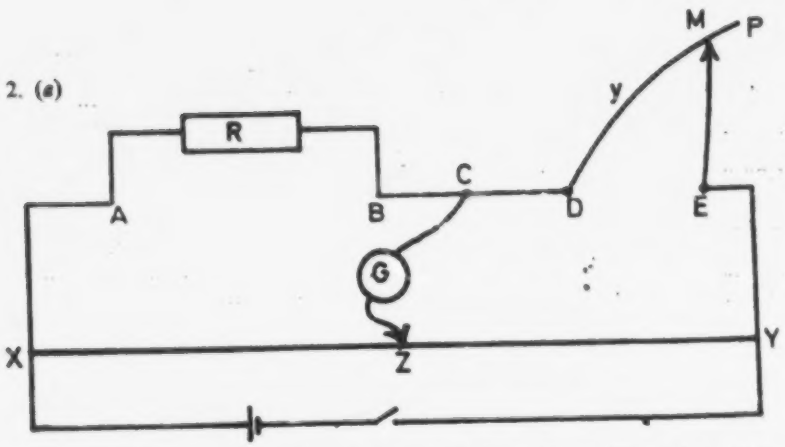
(iii)



The diagram above shows two glass prisms placed apex to apex. Two parallel rays of light meet the two prisms as shown. Copy the diagram and trace the paths of the rays through the prisms and beyond.

[2 marks]

2. (*a*)



Connect up the metre bridge as shown above. The resistor R is a standard resistor carrying a label of the value of its resistance and DP is a bare resistance wire about 105 cm long. Connect the crocodile clip at a point M on the bare resistance wire such that $DM = y = 20.0$ cm and find the balance point Z on the metre bridge. Record the length XZ of the metre bridge wire. Repeat the process for $y = 40$, 60, 75 and 100 cm. Plot a graph of y along the vertical axis and $\frac{100}{XZ}$ along the horizontal axis starting both scales from the origin. Determine the slope of the graph and the value of y when $\frac{100}{XZ} = 0$. State two necessary precautions.

[24 marks]

Turn over

(*b*) (i) If in this experiment, R is balanced against length y of the wire DP and a student wrote down the equation

$$\frac{R}{y} = \frac{XZ}{YZ}$$

Would he be wrong ? Explain your answer.

[2 marks]

(ii) Draw and label a circuit other than the Wheatstone/Metre bridge circuit which can be used to determine the resistance of a given conductor.

[2 marks]

(iii) Write an equation showing the relationship between the resistance R, the length L and the area of cross-section A of a conductor and state the name given to the constant K in the equation.

[2 marks]

3. (*a*) You are provided with an empty beaker which carries a linear scale. Use the pair of vernier callipers provided to determine the internal diameter D of the beaker. Also determine and record the area of cross-section A (in cm^2) of the beaker from the expression,

$$A = \frac{\pi D^2}{4}$$

Now weigh the empty beaker and record the mass Mo. Pour some water into the beaker to a depth h such that h is about 0.5 cm. Measure and record the value of h accurately. Weigh the beaker and its content together and record their total mass M. Determine and record the value Ah, the product of the cross-sectional area and the depth of water in the beaker. Repeat the procedure with h = 1.0 cm, 1.5 cm and 2.5 cm. Record the mass M of the beaker and its contents. In each case, record the value of h accurately and determine the value of Ah. Tabulate your readings. Plot a graph of M on the vertical axis and Ah on the horizontal axis. Determine and record the:

slope of the graph;
intercept on the vertical axis.

State two precautions you have taken to obtain good results.

[24 marks]

(*b*) (i) Obtain an expression to show the relationship between M, Mo, A, h and the density of water d in this experiment.

[2 marks]

(ii) Use your graph to determine the mass of water of depth 4.0 cm in the beaker.

[2 marks]

(iii) If a density bottle of mass 60 g weighs 80 g when completely filled with water and 90 g when completely filled with a liquid, calculate the relative density of the liquid.

[2 marks]

Vita

PERSONAL INFORMATION

Name: Jonathan Nucoln Keister

Place and Year of Birth:
Rotifunk, Sierra Leone, 1948

EDUCATION

1961-1966 Tiama Secondary School

1969-1972 Milton Margai Teachers College, Higher Teachers Certificate

1976-1980 Njala University College, University of Sierra Leone, B.Sc. Education

1988-1990 Queen's University, Master of Education

EXPERIENCE

1972-1973 Teacher, St. Paul's Secondary School, Pujehun

1973-1976 Teacher, Albert Academy, Freetown

1980-1984 Head of Science, Bishop Johnson Memorial Secondary School, Freetown

1984- Lecturer and Acting Head of Physics, Milton Margai Teachers College

AWARDS

1969-1972 Sierra Leone Government Award, Milton Margai Teachers College

1976-1980 Sierra Leone Government Award, Njala University College

1988-1990 CIDA Award, Queen's University, Kingston, Ontario

Appendix 16

END

U.S. Dept. of Education

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